MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 109 No. 2

ANNIVERSARY MEETING OF 1949 FEBRUARY 11

Professor W. M. H. Greaves, President, in the Chair

The election by the Council of the following Fellows was duly confirmed:—

John Atherton Clegg, B.Sc., 12 Veronica Road, Didsbury, Manchester (proposed by J. P. M. Prentice);

Howard Augustus Costigan, Ph.D., M.A., B.Sc., Palatine School, Blackpool, Lancashire (proposed by W. H. Steavenson);

Leland E. Cunningham, University of California, Students' Observatory, Berkeley, California, U.S.A. (proposed by E. M. Lindsay);

George Z. Dimitroff, Shattuck Observatory, Dartmouth College, Hanover, New Hampshire, U.S.A. (proposed by H. Shapley);

Alfred Charles Bernard Lovell, O.B.E., Ph.D., The Quinta, Swettenham, Congleton, Cheshire (proposed by J. P. M. Prentice);

Ann C. Robinson, 84 Barnet Way, Mill Hill, London, N.W. 7 (proposed by C. C. L. Gregory);

Robert Waland, University Observatory, St. Andrews, Scotland (proposed by E. Finlay-Freundlich); and

Patrick Arthur Wayman, B.A., Solar Physics Observatory, Cambridge (proposed by E. H. Linfoot).

The election by the Council of the following Junior Member was duly confirmed:—

Peter Coles Price, Fairlawn, 35 The Croft, High Barnet, Herts (proposed by Lydia A. Brown).

Eighty presents were announced as having been received since the last meeting, including:—

G. B. Kukarkin and P. P. Parenago, *General Catalogue of Variable Stars* (presented by the Academy of Sciences of the U.S.S.R.).

The President announced that Professor O. Struve would deliver the George Darwin Lecture at the Ordinary Meeting on 1949 October 14, taking Spectroscopic Binaries as his subject.

After delivering his address on its award (see p. 258), the President presented the Gold Medal to Professor Sydney Chapman.

The President, in presenting the Jackson-Gwilt Medal and Gift to Mr Algernon Montague Newbegin, to whom it had been awarded for his observations of solar phenomena during the past forty years, said:

"A Jackson-Gwilt Medal and Gift has been awarded to Mr Algernon Montague Newbegin for his observations of solar phenomena during the last forty years. In setting forth the reasons which have led to this award I propose to refer to Newbegin's more recent observational work first. We have already been concerned to-day with the subject of solar flares, and it is unnecessary for me to stress the importance of gaining all the knowledge we can of these eruptions. The systematic intensive study of flares was stimulated by Hale's invention of the spectrohelioscope, and in Newbegin we in Great Britain have been fortunate in having amongst us at the right time an enthusiastic amateur astronomer who was quick to appreciate the value and potentialities of this instrument. In 1932 he obtained blue-prints from Hale, and he set to work to make a spectrohelioscope, which was completed in 1934; its construction, apart from the optical parts, having been largely carried out in his own workshop at Worthing. He has given us a full description of this instrument in the *Monthly Notices* for 1934 December.

"His object in constructing this spectrohelioscope was to extend his studies of prominences from the limb to the disk, but to these prominence studies he added the observation and classification of flares, and from 1935 onwards he participated in the organized international plan for their study, his observations being contributed regularly to the *Quarterly Bulletin of Solar Activity*. I am informed that his observing books contain a wealth of detailed information, and I venture to express the hope that this information will be made more generally available.

"I have referred to his studies of prominences, and I must refer especially to his valuable series of prominence observations which have appeared at regular intervals in the *Journal of the British Astronomical Association*. When Maunder ceased in 1925 to be the Director of the Solar Section of the Association, it was natural that Newbegin should be chosen to succeed him; in his capacity as Director, Newbegin was responsible for compiling the fifteenth and sixteenth Reports of the Section.

"I must also refer to his skill as a draughtsman, a faculty which enabled him to illustrate his observations. As an example of this, reference may be made to his sketches portraying the chromospheric phenomena of 1929 April 6–10 (*Journal B.A.A.*, **39**, 292) associated with an active spot group. The sketches show vividly the "motion forms" associated with a bright $H\alpha$ reversal.

"In honouring Newbegin we are honouring one of the band of skilful and enthusiastic amateurs to whom British Astronomy has owed much. It was with regret that we heard of his decision to retire from observational work at the end of 1946, but in this connection it is fitting that I should refer to his generosity and public spirit. He has presented the whole of his solar equipment to the Royal Greenwich Observatory, and his dome, photoheliograph and spectrohelioscope will be incorporated in the new Solar Buildings at Herstmonceux Castle.

"Mr Newbegin:—Your contributions to the study of solar phenomena have been of such a nature that it was inevitable that we should honour you, and this Medal and Gift are a symbol of the respect with which we regard your work. We regret that you have retired from active observation, but we find some consolation in the reflection that you may now find time to make your detailed studies of flares generally available. With the Medal and Gift go our very best wishes."

ANNUAL GENERAL MEETING OF 1949 FEBRUARY 11

Professor W. M. H. Greaves, President, in the Chair

The Minutes of the preceding Annual General Meeting were read, confirmed and signed.

The Minutes of the Special General Meeting of 1948 May 14 were read, confirmed and signed.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year.

The Secretary read extracts from the Narrative Report of the Council.

The Report of the Honorary Auditors was read (see p. 126).

The Deputy Treasurer, in the absence of the Treasurer, gave a brief explanation of the accounts and a survey of the Society's financial position.

A vote of thanks to the Honorary Auditors of the Treasurer's Accounts for 1948 was proposed and carried unanimously.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Honorary Auditors and the President's Address on the award of the Gold Medal.

The Scrutineers reported to the President the result of the ballot, in which two candidates for the Council had received an equal number of votes. The President gave a casting vote and the names of the Officers and Council elected for the ensuing year were then read to the Meeting. (The list of names is given on p. 276).

The newly elected President (Professor W. M. Smart) and the Secretaries (Professor R. O. Redman and Dr A. Hunter) then took their places.

The thanks of the Society were given to the retiring President (Professor W. M. H. Greaves), Vice-Presidents (Professor H. H. Plaskett and Mr P. J. Melotte), Secretary (Professor W. H. McCrea), and other retiring members of Council.

The thanks of the Meeting were also given to the Scrutineers of the ballot.

The Meeting then adjourned.

REPORT OF THE COUNCIL TO THE HUNDRED AND TWENTY-NINTH ANNUAL GENERAL MEETING OF THE SOCIETY

1. *General.*—The first meeting of the Society to be held outside London took place in Edinburgh on October 29. The Council believes that the Society may view with satisfaction the success of the precedent so established. This success was due in the first place to very effective cooperation on the part of the Astronomical Society of Edinburgh, and in the second to the exceedingly congenial conditions under which it was possible to hold the meeting itself, thanks to the hospitality of the Royal Society of Edinburgh. The interest of the occasion was notably enhanced, particularly for visiting Fellows, by the opportunity to attend the Lorimer Lecture of the Astronomical Society of Edinburgh on the previous evening, after which Fellows were entertained by the Council of that Society, and by visits to the Royal Observatory, Edinburgh, and to the University Observatory, St. Andrews, where Fellows were given luncheon by the Court of the University. Finally, the Council deeply appreciates the fact that the Lord Provost and Magistrates of the City of Edinburgh honoured the occasion by giving a Civic Reception to visiting astronomers on the afternoon of October 28. The Council gratefully accepted grants towards the expenses of the meeting from the Committee of the Cormack Bequest, administered by the Royal Society of Edinburgh, and from the Astronomical Society of Edinburgh. To all the authorities who in all these ways shared in making the Society's visit to Edinburgh so memorable, the Council has expressed the cordial thanks of the Society.

It is the hope of the Council that one such additional meeting will be held during each calendar year. The Council is planning to hold the next one in Manchester on 1949 July 1 with the cooperation of the Manchester Astronomical Society and the Director of the Physical Laboratories of the University of Manchester.

The other notable special event of the year was the Conversazione on July 23. The date was fixed as late as possible before the holiday period, so as to enable the Society to entertain delegates passing through England on their way to attend the Assembly of the International Astronomical Union in Zürich during August. Fellows were gratified by the fact that on this occasion there were more exhibits and demonstrations than on such occasions in the past.

The organization of these two special events occupied a good deal of the Council's attention during the year. The rest of this Report may appear to record a smaller number of non-routine activities than those of recent years. Nevertheless the Council and its Officers and Committees have been kept very fully occupied in what may be classed under the general heading of the overhauling of affairs concerning the Society's administration and property. While the vast majority of the Society's activities had survived through the war years on a somewhat reduced scale, the subsequent intensification of these activities, coupled with post-war difficulties, proved more than existing arrangements could contend with

in their inevitably "dilapidated" state. An obvious example on the material side was the breakdown of the heating system towards the end of 1947. An example partly on the material and partly on the organizational side was a partial breakdown of the arrangements for the distribution of publications. The Council believes that all such problems as have so far arisen have now been dealt with.

2. *Eddington Gold Medal.*—The appeal in connection with the establishment of this award was launched in April. By the end of the year, little more than half the sum estimated to be necessary had been received. The Council gained the impression that some confusion had arisen between this appeal and an earlier one made altogether independently by another body. The earlier appeal had in view the commemoration of Sir Arthur Eddington's work in certain fields not restricted to astronomy, and the Society was not in any way involved in its sponsorship. The Society's recent appeal, on the other hand, aims solely at the commemoration of his services to astronomy by means of an award to be made at suitable intervals by the Society itself.

3. *Isaac Newton Observatory.*—The Council has appointed Dr E. Finlay-Freundlich as the Society's representative on the Board of Management for the period 1949 January 1 to 1952 December 31. He succeeds Professor A. O. Rankine, who retired on 1949 December 31 in accordance with the rules governing the Board's constitution.

The first Report of the Board forms Section X of the Report of the Astronomer Royal, presented to the Board of Visitors of the Royal Observatory, Greenwich, on 1948 June 5.

4. *Membership.*—The Council records with regret the deaths of two Associates (Henri Alexandre Deslandres and Leon Herrero (1947)) and fifteen Fellows; their deaths occurred in 1948 except where an earlier year is indicated.

E. R. Bartlam
*Frederick William Bateman
James Blackhall
Lêon Cap
*David Carder-Davies
Ella Katherine Church
*Ben Dudley
*Algernon Charles Gifford
Richard Francis Turney Granger
Henden Egerton Houghton (1947)
*Dennis F. MacCarthy
Aylmer Joseph Probyn Maude
William Nicholas Roseveare
John Johnston Ross
Rev. James Peter Rowland, S.J.
John Johnson Shaw

* Life Fellow.

Obituary Notices of the Associates and some of the above Fellows are given on pages 141 to 151.

A table giving detailed statistics of the Membership of the Society on 1949 January 1 is given on page 127.

The last Report recorded the institution of Junior Membership of the Society. It is considered satisfactory that during the first year of its existence, eleven persons have been elected to such membership.

5. *Finance.*—The Annual Accounts have been presented in the same form as in the previous year.

The late Mr Carder-Davies bequeathed to the Society the sum of £3000, without condition, but asked that no part be spent on any purpose controlled or suggested by the Government. The bequest has been received from the Executors and has been invested, £1200 in British Electricity 3 per cent Guaranteed Stock 1968/73, and the remainder in Treasury 2½ per cent 1976; these investments are added to the General Funds.

The Coleman refractor has been sold for £700 to the Port Elizabeth Centre of the Astronomical Society of South Africa, where it is to form part of a People's Observatory. The sale has relieved the Society of further expenditure at Headley for rent of the Observatory paddock, for caretaking and for insurance. The proceeds of the sale have been invested in British Electricity 3 per cent Guaranteed Stock 1968/73 and added to Capital Funds.

The Council has approved the transfer of £250 from the E. W. Brown Trust Fund to the General Account, to be used for the general purposes of the Society.

A grant of £750 towards the cost of the publication of the *Monthly Notices* and the *Geophysical Supplement* has been received through the Royal Society from the Parliamentary Grant-in-Aid for Scientific Publications.

The increase in the Annual Contribution to three guineas took effect from 1948 January 1. Despite the increase in the amounts received from Fellows, the transfer of £250 to the General Account from the E. W. Brown Trust Fund, and the grant of £750 towards the costs of printing from the Parliamentary Grant-in-Aid for Scientific Publications, there is a deficit on the year of £968. This is in part due to the reserve provided to cover the cost of the arrears of printing having proved inadequate, because of a further heavy increase in printing costs early in the year, and in part due to a large expenditure for binding war-time periodicals. The position has to be faced, however, that the normal income of the Society is insufficient to meet the normal expenditure. The Annual Contribution has been increased by 50 per cent; the investment income tends to decrease on account of conversions to stocks bearing a lower rate of interest, while the cost of printing and various other items of expenditure have increased by at least 100 per cent.

6. *Meetings during* 1948.—The normal number of Ordinary Meetings were held, together with the additional meeting in Edinburgh mentioned in paragraph 1 and one Special General Meeting. The President (Professor W. M. H. Greaves) delivered his address on "The Photometry of the Continuous Spectrum" at the Anniversary Meeting; this is printed in *Monthly Notices*, Vol. **108**, pages 131–151; the George Darwin Lecture was delivered at the April meeting. The October meeting was notable on account of the number of visiting Fellows from abroad who addressed the Society on their work and that of their observatories: these were Dr J. Jackson (Royal Observatory, Cape of Good Hope), Miss M. Harwood (Maria Mitchell Observatory, Nantucket, U.S.A.), Dr R. v. d. R. Woolley (Commonwealth Observatory, Canberra, Australia), Rev. D. J. K. O'Connell, S.J. (Riverview College Observatory, New South Wales) and Dr C. W. Allen (Commonwealth Observatory, Canberra). Visitors who spoke at other meetings were Dr J. Tuominen (Helsinki) and Dr F. Zwicky (Mount Palomar). The average attendance of Fellows (as shown by the signatures in the Attendance Book, and excluding visitors) was 75 as compared with 70 in 1947.

7. *Geophysical Discussions.*—The Geophysical activities of the Society have been well maintained during 1948. Six discussions were held, one of these, on "Post-Glacial Climatic Change", in conjunction with the Royal Meteorological Society. These discussions have proved very popular, the average attendance at the five held in Burlington House was 81. There has been a small, but very welcome, increase in the number of geophysicists who have joined the Society.

8. *Award.*—The Council awarded the Gold Medal of the Society to Professor Bertil Lindblad for his work on the rotation of the Galaxy, on the dynamics of stellar systems and on stellar luminosities.

9. *George Darwin Lecture.*—Professor Bertil Lindblad, of Stockholm Observatory, Sweden, gave the George Darwin Lecture at the Ordinary Meeting on April 9, taking as his subject "The Dynamics of Stellar Systems". This address is printed in *Monthly Notices*, Vol. **108**, pages 214–235.

10. *Publications and Printing.*—During the year 1948 the Society has published and distributed *Monthly Notices*, Vol. **106**, No. 6, Vol. **107**, Nos. 1, 2, 3, 4, 5/6, Vol. **108**, Nos. 1, 2, 3, 4, *Geophysical Supplement*, Vol. **5**, Nos. 6 and 7, and *Occasional Notes*, No. 12. There are in print, but not yet published, *Monthly Notices*, Vol. **108**, No. 5 and *Geophysical Supplement*, Vol. **5**, No. 8.

It was with considerable satisfaction that the Council was able, in the middle of the year, to announce that all arrears of printing for *Monthly Notices* and *Geophysical Supplement* had been dealt with, and that in future the delay between the acceptance by the Council of the final draft of a paper and its publication should be not more than a few months. In order to maintain this position, the Council has decided that it will be more expedient to issue *Monthly Notices*, Vol. **109** in six parts rather than to attempt at the present stage to revert to the pre-war number of parts. Also the Council intends to issue the *Geophysical Supplement* as regularly as possible once in each six months.

The Council much regrets that during the early part of 1948 the distribution of the Society's publications, not only to Fellows but also to institutions on the Exchange List and to subscribers, suffered some temporary disorganization. This was owing to a variety of causes, among them the difficulty of securing the plates from which the addresses of recipients are printed. The system of distribution has now been thoroughly reorganized and appears to be in good working order. Every effort was made to rectify any earlier omissions in the distribution, but if there are still any outstanding it is hoped that those concerned will notify the Society's office without delay.

Both for the gratifying improvement in the printing position and for the efficient reorganization in the distribution the Council is indebted to the cooperation of Messrs Taylor & Francis, Ltd. and the members of their staff particularly concerned.

It was found that the Society's recent paper allocation had been based upon an underestimate of the pre-war consumption. As a result of negotiation between the Council, the printers and the Board of Trade, this situation was rectified in April. While all possible economy in the use of paper has still to be enforced, the improved allocation has been an essential factor in overtaking arrears of printing.

11. *Exchange of Publications.*—A number of fresh exchanges have been arranged since the publication of the list in the last Annual Report, but it is not proposed to issue a revised list more than once every five years approximately. The effective operation of the exchange system is still giving the Council some concern, and it has recently appointed one of its members to supervise this until it can be put in easy running order. Part of the difficulty arises from obstacles to the easy transmission of printed matter to certain countries.

12. *Library.*—The Library has not been used as much as in 1947. In 1948 the number of books borrowed was 425 by 100 different borrowers, as compared with 608 books and 134 different borrowers in 1947. Visitors to the Library for consultation are only slightly less than last year, being about 90 a month compared with 95 a month in 1947.

One list of *Additions to the Library*, covering additions up to 1947 December 31, was circulated with *Monthly Notices* during the year. A list of those who presented gifts to the Library, other than by exchange, is given on page 139.

Many back numbers to complete the Society's series of periodicals have been received during the year and the possibility of completing others by photostat copies is being considered.

The serials sent to the binders last year were returned early in the year and this year a further consignment has been sent, which is to be returned early next year. A consignment of serials has also been sent to another firm and this has been satisfactorily completed. Use has been made of *slip cases* for some less important serials and this practice has helped towards the neater appearance of the shelves, though there is still much binding to be done.

Preliminary steps have been taken in the re-arrangement and re-cataloguing of the Library and a cabinet for the classified catalogue has been purchased. It has been decided to adopt the Library of Congress system of classification for the catalogue and the World List of Scientific Periodicals system for cataloguing periodicals in the Society's Library. In this latter connection, details of the Society's holdings of periodicals have been supplied for inclusion in the 1947 edition of this publication.

13. *Astronomical photographs.*—A supplement to the *Catalogue* of slides, prints and films in the Society's collection is being prepared and will shortly be printed. The situation regarding stocks of photographs available for purchase by Fellows continues to improve.

A reproduction of Dr W. H. Wright's film of Jupiter and its satellites has been made available for hire to Fellows. The demand for the use of the Society's films has been considerable.

14. *Instruments.*—The Coleman 8-inch refractor has been sold to the Port Elizabeth Centre of the Astronomical Society of South Africa (see *Monthly Notices*, **108**, 307, 1948). This has enabled the Council to terminate the arrangement made in 1942 (see *Monthly Notices*, **103**, 49, 1943) for the storage of instruments at the Headley Observatory, which has now been dismantled.

15. *The Society's premises.*—The hot-water heating system remained out of action for the remainder of the winter 1947–48 (see *Monthly Notices*, **108**, 11, 1948) but the full programme of meetings of the Society and its guest societies was

carried through in moderate comfort with the help of temporary arrangements, recorded in the last Report (with the exception of one meeting of the London Mathematical Society which had to be held elsewhere before the arrangements were in full operation). A new boiler was purchased and installed by the Ministry of Works during the summer and has been in operation since October.

The Basement and the "Herschel cupboard" were redecorated during August and minor repairs to the furniture of the meeting-room have been effected.

16. *The Society's Staff.*—The appointment of Miss M. F. M. Garratt, B.Sc., as Assistant Secretary, has been confirmed. Miss E. Wadsworth, M.A., commenced her duties as Librarian (part-time) on January 1 and has been re-appointed to the post for the year 1949 January 1 to December 31.

17. "*The Observatory*".—The Bye-laws concerning Junior Members necessarily make no mention of their receiving *The Observatory* which, though distributed to Fellows, is not a publication of the Society. The Editors of *The Observatory* have, however, offered to supply copies for Junior Members and the necessary arrangements are now being made.

18. *Guest Societies.*—The British Astronomical Association and the London Mathematical Society (save for the one meeting mentioned above) held their normal number of meetings in the Society's rooms. Accommodation was granted to the Royal Society for meetings of its Scientific Information Conference, to a committee of the Board of the Isaac Newton Observatory and to the Research Committee of the Norman Lockyer Observatory.

19. *Representation of the Society.*—The Council has made the usual provision for the regular representation of the Society on various outside bodies. It appointed Miss F. M. McBain (Editor of *Monthly Notices*) as the Society's representative at the Scientific Information Conference, June 21 to July 12. The Society was represented by Mr C. C. L. Gregory at the funeral of Mr D. Carder-Davies in January, and Professor H. Dingle (Vice-President) at the dedication at Headley on May 15 of the screen commemorating the Rev. T. E. R. Phillips.

REPORT OF THE AUDITORS FOR THE YEAR 1948

We have examined the accounts of the Society and approve the various items of expenditure. We note with some concern, however, that there is still an excess of expenditure over revenue and that, in spite of the increase in the annual subscription, this is almost as large as the deficit for the previous year.

We have checked the official list of Fellows against subscriptions received. We are happy to note that there is no great increase in the number of resignations. On the other hand, there is only a small increase in the total membership, although there are 62 new Fellows and 11 Junior Members. These additions are offset by the removal from the official list of a large number of Fellows whose contributions were unobtainable under war conditions. We are glad to note that the list of names on the Suspense Account is very much shorter. We also note with satisfaction the support which has been forthcoming for the new class of Junior Membership.

We have examined the premises of the Society. The heating has been much improved by the installation of a new boiler, and the basement has been redecorated throughout. We endorse the recommendation of the Auditors of the previous two years that attention be given as soon as possible to improving the artificial lighting, at any rate in the main library, and to repairing the carpet in the upper library.

We gratefully acknowledge the help and cooperation of the Assistant Secretary, who provided us with all the information that we required.

E. M. BURBIDGE.
R. W. B. PEARSE.

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Fellows			Junior Members	Associates	Total
			Compounders	Annual Contributors	Non-active Fellows			
1948 January 1	1	5	210	667	38	...	47	968
Since elected	...	...	+ 2	+60	...	+11	+ 4	...
Elected 1947, declared null and void	...	...	...	− 2	...	...	...	...
Deceased 1948	...	...	− 6	− 9	...	...	− 2	...
Deceased prior to 1948, death not notified	...	...	− 2	− 3	...	...	...	...
Resigned 1948	...	...	...	−19	...	...	...	...
Resigned 1947, noted 1948 ...	...	...	...	− 4	...	...	...	...
Resigned 1946, noted 1948 ...	...	...	...	− 1	...	...	...	...
Since compounded	...	...	+11	−11	...	...	...	...
Removed from list...	...	...	...	− 5	...	...	...	...
Removed from list 1947, not counted until 1948	...	...	...	− 1	...	...	...	...
Suspense Account :—								
Deducted 1948 :								
(*a*) Deceased (date unknown) Bye-law 26A	...	...	...	...	− 1	...	...	...
(*b*) Removed from list :—								
" War Conditions " ...	...	...	...	...	− 4	...	...	...
Bye-law 26A	...	...	...	...	− 3	...	...	...
Bye-law 26B	...	...	...	...	− 5	...	...	...
(*c*) Removed from list 1947, not counted until 1948 :								
" War conditions " ...	...	...	...	...	− 3	...	...	...
(*d*) Resigned 1948 :—								
Bye-law 26A	...	...	...	...	− 2	...	...	...
Bye-law 26B	...	...	...	...	− 1	...	...	...
Transferred 1948 :								
(*a*) From " War Conditions " 1947 to Active	...	...	...	+ 4	− 4	...	...	...
(*b*) From Bye-law 26A 1947 to Active	...	...	...	+ 2	− 2	...	...	...
1949 January 1	1	5	215	678	13	11	49	972

(N.B.—Eight Associates are also Fellows, and are therefore counted twice in the above table.)

Balances, 1948 January 1 :—															
In hand of Assistant Secretary, on Petty Cash Account													16	4	8
At Westminster Bank, on Current Account as per Pass Book										395	10	4			
Less Cheques not presented										113	10	4			
													282	0	0
At Westminster Bank, on " B " Account :—															
A. S. Williams Bequest													52	10	0
At Westminster Bank, on " C " Account :—															
Trust Funds, as per Pass Book								£553	18	6					
Less Cheques not presented								2	5	0					
											551	13	6		
Sales of Duplicate Books Fund											14	0	7		
													565	14	1
At Post Office Savings Bank :—															
General Fund											3,874	8	2		
" C " Account											705	8	4		
Staff Pension Fund											476	4	1		
													5,056	0	7
At London Savings Bank :—															
Ordinary Department (including £250 A. S. Williams Bequest) ...											1,184	18	0		
Special Investment Department											599	4	9		
													1,784	2	9
															7,756 12 1
Legacy from D. Carder-Davies Bequest															3,000 0 0
Proceeds of sale of Coleman Refractor															700 0 0
Parliamentary Grant-in-Aid for Scientific Publications, received through the Royal Society for 1948															750 0 0
E. W. Brown Bequest, amount applied to general purposes of the Society ...															250 0 0
Eddington Memorial Fund : Subscriptions received															249 15 8
Dividends on Investments													641	2	0
Interest on Savings Banks Deposits													148	6	6
Income Tax refunded : 1947 April to December											131	13	2		
1948 January to April											83	14	0		
													215	7	2
Sales of Publications :—															
For 1948											616	13	8		
Due in 1947											151	12	11		
1949 in advance											39	2	0		
													807	8	7
Reprints :—															
For 1948													64	5	3
Sale of Photographs and Hire of Slides, 1948													41	10	0
Hire of Films													28	10	6
Miscellaneous Receipts :—															
London Mathematical Society											35	0	0		
Assistant Secretary and Librarian, Contributions to Pension Scheme ...											65	0	0		
Postages repaid : 1947								£7	9	10					
1948								34	12	1					
Postages 1949, paid in advance								2	16	0					
											44	17	11		
Excess on Contributions												1	4		
British Astronomical Association, 1948 January to October											90	0	0		
Scientific Computing Service												7	6		
Conversazione, Sale of Tickets											65	10	0		
Edinburgh Meeting, Grants :—															
Royal Society Edinburgh (McCormack Bequest) ...								£63	0	0					
Astronomical Society of Edinburgh								10	0	0					
											73	0	0		
													373	16	9
															2,320 6 9
Received on Account of Contributions :—															
498 Annual Contributions, 1948								£1,568	14	0					
6 Annual Contributions, 1948, partly paid in 1947 ...								7	7	0					
27 Partial Contributions, 1948								50	17	0					
											1,626	18	0		
5 Institutional Membership Fees											15	15	0		
11 Junior Members' Annual Contributions											11	11	0		
53 Admission Fees, 1948								£111	6	0					
31 First Contributions at £3 3s.								97	13	0					
20 First Contributions at £1 1s.								21	0	0					
											229	19	0		
													1,884	3	0
Arrears paid off :—															
1 Fellow's Annual Contribution, 1945								£2	2	0					
1 Fellow's Annual Contribution, 1946								2	2	0					
21 Fellows' Annual Contributions, 1947								44	2	0					
1 Institutional Membership Fee, 1947								2	2	0					
7 Admission Fees, 1947								14	14	0					
7 First Contributions, 1947								7	7	0					
											72	9	0		
Contributions in Advance, received 1948 :—															
36 Annual Contributions and 4 Partial for 1949								£116	17	0					
1 Annual Contribution and 1 Partial for 1950								4	9	0					
1 Annual Contribution, 1951								3	3	0					
1 Junior Member's Contribution, 1949								1	1	0					
											125	10	0		
Compositions :—															
1 Initial								£47	5	0					
12 Reduced								303	0	6					
Special Appeal Receipts								5	3	0					
											355	8	6		
													553	7	6
															2,437 10 6
" C " Account :—															
Dividends on Investments													206	0	11
Income Tax refunded													29	9	3
Interest on Post Office Savings Bank Account													17	12	6
Sales of Duplicate Books and Instruments													—	—	—
															253 2 8
Cash transferred from Post Office Savings Bank to Westminster Bank, Current Account															1,200 0 0

Account

PAID

	£ s. d.	£ s. d.	£ s. d.
Office Staff, including Librarian :—			
Salaries	815 18 1		
Income Tax on Salaries	102 0 0		
National Insurance	26 10 2		
Assistant Secretary and Librarian : Pension Premiums (Society's Contributions £70 ; Staff Contributions £86 5s. 11d.)	156 5 11		
		1,100 14 2	
Porter and Wife : Wages and Cleaning	272 7 0		
National Insurance	17 9 0		
Pension Contribution	13 0 0		
		302 16 0	
Charwoman : Wages		32 3 6	
			1,435 13 8
Insurance		15 15 7	
Telephone		33 19 10	
			49 15 5
Printing, etc. :—			
Monthly Notices (Vol. **106**, Nos. 5 and 6)	496 5 5		
Monthly Notices (Vol. **107**, Nos. 1 to 6)	1,907 0 9		
Occasional Notes (No. 11)	127 15 4		
Geophysical Supplement (Vol. **5**, No. 6)	142 6 4		
Reprints	61 16 6		
List of Fellows	126 16 6		
Amendments to Bye-Laws	3 13 6		
Miscellaneous, including notices of Meetings	176 9 0		
Photo-engraving	171 15 11		
Lists of Additions to Library	14 5 0		
		3,228 4 3	
Paper supplies for publications		544 12 2	
			3,772 16 5
Postages and Packing :—			
Monthly Notices, etc.		262 16 0	
Office postages		143 19 6	
			406 15 6
Stationery and Office Expenses		126 1 5	
Heating and Lighting		137 3 11	
Accountants' Fees		47 5 0	
Subscription to National Central Library		1 1 0	
Subscription to A.S.L.I.B.		3 3 0	
I.A.U. Telegrams		16 3 5	
Authorized Travelling Expenses		10 4 2	
Repairs, Fittings and Fixtures		27 18 5	
House Expenses and Laundry		133 6 2	
Expenses of R.A.S. Meetings and Committees		55 13 10	
Bank Charges and Cheque Books		3 5 4	
Library Expenses (including Cabinet for Card Catalogue £70 9s. 4d.)		88 8 1	
Gold Medal		10 15 0	
Miscellaneous Expenditure		22 5 0	
			682 13 9
Expenditure charged to Reserve Accounts :—			
Repairs		14 7 9	
Reproduction of Slides and Prints		88 16 11	
Binding Periodicals		105 17 0	
Purchase of Books from Potter Fund		9 1 8	
			218 3 4
Binding Periodicals		247 7 9	
Less Provided out of Reserve (*see above*)		105 17 0	
			141 10 9
Headley Observatory (closed July 1948) :—			
Rent of Observatory Paddock	2 10 0		
Mr. Maskell for care of site	7 10 0		
		10 0 0	
Less Contribution from British Astronomical Association	16 8		
Contribution from Dr. R. L. Waterfield	2 1 8		
		2 18 4	
			7 1 8
Block Subscription to *The Observatory*			125 0 0
Eddington Memorial Fund : Printing and Postage			13 9 0
Miscellaneous Expenditure :—			
Freight and Carriage on Refractor to South Africa (recoverable)		42 19 1	
Expenditure on Films		15 4 1	
Conversazione Expenses		133 2 9	
Edinburgh Meeting Expenses		68 5 8	
			259 11 7
Investments of Legacy from D. Carder-Davies Bequest :—			
£2,239 13s. 8d. Treasury 2½% Stock, 1975		1,770 9 0	
£1,200 0s. 0d. British Electricity 3% Guaranteed Stock, 1968/73		1,229 11 0	
			3,000 0 0
Investment of proceeds of Sale of Coleman Refractor :—			
£683 2s. 0d. British Electricity 3% Guaranteed Stock, 1968/73			700 0 0
Expenditure on Trust Accounts :—			
Turnor and Horrocks Fund (Library)		23 8 6	
Harry Watson Fund (Library)		104 16 11	
George Darwin Lectureship Fund		50 0 0	
E. W. Brown Trust Fund		250 0 0	
Sales of Duplicate Books Fund		9 9 0	
			437 14 5
Cash transferred to Westminster Bank, Current Account, from Post Office Savings Bank			1,200 0 0
Balances, 1948 December 31 :—			
In hand of Assistant Secretary, on Petty Cash Account		6 11 1	
At Westminster Bank on Current Account, as per Pass Book	392 1 7		
Less Cheques not presented	157 0 0		
	235 1 7		
Add Foreign draft not credited till 1949	3 7 4		
		238 8 11	
At Westminster Bank, on "B" Account (A. S. Williams Bequest)		52 10 0	
At Westminster Bank, on "C" Account :—			
Trust Funds, as per Pass Book (includes Sales of Duplicate Books Fund £4 1s. 2d.)	367 11 10		
Less Cheques not presented	4 2 0		
		363 9 10	
At Post Office Savings Bank :—			
General Fund	2,766 5 2		
"C" Account	723 0 10		
Staff Pension Fund at 1947 December 31 £476 4 1			
Add Interest, 1948 11 18 0			
	488 2 1		
		3,977 8 1	
At London Savings Bank :—			
Ordinary Department (including £250 A. S. Williams Bequest)	1,214 10 0		
Special Investment Department	614 4 3		
		1,828 14 3	
			6,467 2 2
			£18,917 7 8

Dr. *General Fund Revenue Account*

	£ s. d.	£ s. d.
To Salaries and Wages, including Pension Premiums and National Insurance		1,352 0 5
„ Insurance and Telephone (after adjusting Reserves)		49 15 5
„ Printing, etc. (after adjusting Reserves)	3,492 16 5	
Less Amount received from the Parliamentary Grant-in-Aid for Scientific Publications through the Royal Society for 1948	750 0 0	
		2,742 16 5
„ Posting and Packing (after adjusting Reserves)		324 0 11
„ *General Expenses* (*after adjusting Reserves*) :—		
Stationery and Office Expenses	124 13 5	
Lighting and Heating	132 3 11	
Travelling Expenses	12 4 2	
Subscriptions to National Central Library and A.S.L.I.B.	4 4 0	
Accountants' Fees, 1948 £31 10 0		
Special Assistance, 1948 15 15 0		
	47 5 0	
Gold Medal	10 15 0	
Office Furniture and Fittings, including repairs	147 8 9	
I.A.U. Telegram Service	16 3 5	
House Expenses	98 13 2	
Meeting Expenses	59 2 0	
Sundries	43 9 1	
		696 1 11
„ Block Subscription to *The Observatory*		125 0 0
„ Purchase of Books from Potter Fund		7 7 8
„ Headley Observatory, Expenses *less* Refunds		7 1 8
„ Annual Reserve for Repairs		40 0 0
„ Binding of Periodicals, etc.	318 15 3	
Less Provided out of Reserve	105 17 0	
		212 18 3
„ Reproduction of Photographic Slides and Prints	106 10 7	
Less Provided out of Reserve	101 18 11	
		4 11 8
„ Films, Hire and Expenses		15 4 1
„ Conversazione : Expenses	133 2 9	
Less Sale of Tickets	65 10 0	
		67 12 9
„ Edinburgh Meeting Expenses		68 5 8
		£5,712 16 10

One Year to 1948 *December* 31 — *Cr.*

	£ s. d.	£ s. d.	£ s. d.
By *Amounts received from Fellows* :—			
1 Arrear for 1945	2 2 0		
1 „ „ 1946	2 2 0		
21 Arrears „ 1947	44 2 0		
1 Institutional Membership Fee, 1947	2 2 0		
7 Admission Fees, 1947	14 14 0		
7 First Contributions, 1947	7 7 0		
527 Annual Contributions, 1948	1,660 1 0		
33 Partial Payments, 1948	65 6 0		
5 Institutional Membership Fees	15 15 0		
11 Junior Members' Annual Contributions	11 11 0		
53 Admission Fees	111 6 0		
51 First Contributions	118 13 0		
		2,055 1 0	
Composition Fees :—			
Initial Fee	47 5 0		
Reduced Fees	303 0 6		
Special Appeal	5 3 0		
	355 8 6		
Less Transferred to Reserve Account	355 8 6		
	— — —		
Add Amount brought to Credit for the year	127 2 1		
		127 2 1	
			2,182 3 1
„ Interest and Dividends received (gross)		850 0 9	
„ Interest on Bank Deposit Accounts received		136 8 6	
			986 9 3
„ Sales of Publications, Photographs and Miscellaneous Receipts for the year			1,252 18 2
„ E. W. Brown Trust Fund, Grant towards General Funds of the Society			250 0 0
„ Grants received for Edinburgh Meeting			73 0 0
„ Deficiency one year to date			968 6 4
			£5,712 16 10

Note.—Fellows' 1948 *Contributions not received were* :—

88 Unpaid at 1948 December 31 at £3 3*s.* 0*d.*	277 4 0
Balance payments required at 1948 December 31 to complete contributions	33 8 0
Total for the year	£310 12 0

This amount has been added to the Suspense Account and is not included in this Revenue Account.

Balance Sheet

	£ s. d.	£ s. d.	£ s. d.
General Fund :—			
As at 1947 December 31	21,532 1 5		
Add D. Carder-Davies Bequest	£3,000 0 0		
Proceeds of Sale of Coleman Refractor ...	700 0 0		
	3,700 0 0		
	25,232 1 5		
Less Excess of Expenditure over Income, 1948	968 6 4		
		24,263 15 1	
Trust Funds :—			
Capital as at 1947 December 31	6,707 0 3		
Income Balances at 1948 December 31	1,081 19 1		
Income Tax on Trust Funds, 1948 April–December, not yet refunded	19 10 8		
		7,808 10 0	
Arthur Stanley Eddington Commemoration Fund :—			
Amount received to date, *less* expenses £13 9*s.* 0*d.*		236 6 8	
Reserves :—			
Repairs and Maintenance :			
As at 1947 December 31	£280 0 0		
Less Expenditure, 1948	14 7 9		
	265 12 3		
Add Set aside for 1948	40 0 0		
	305 12 3		
Replacements of Photographic Slides and Prints :			
As at 1947 December 31	101 18 11		
Less Part Expenditure for 1948	101 18 11		
Binding War-time Periodicals :			
As at 1947 December 31	105 17 0		
Less Part Expenditure for 1948	105 17 0		
Sales of Duplicate Books Fund :			
As at 1947 December 31	14 0 7		
Less Books purchased	9 9 0		
	4 11 7		
		310 3 10	
Composition Fees Reserve Fund :—			
As at 1947 December 31	1,762 19 4		
Received in 1948	350 5 6		
Special Appeal in 1948	5 3 0		
	2,118 7 10		
Less 6 per cent transferred to Revenue Account	127 2 1		
		1,991 5 9	
Staff Pension Fund :—			
As at 1947 December 31	476 4 1		
Add Interest for 1948	11 18 0		
		488 2 1	
Amounts received in advance :—			
Contributions :			
1949 paid in 1945 (£1 12*s.* 0*d.*, *less* £1 1*s.* 0*d.* applied to 1948	11 0		
1949 paid in 1946 (£2 12*s.* 0*d.*, *less* £1 1*s.* 0*d.* applied to 1948	1 11 0		
1949 paid in 1947	1 17 0		
1949 paid in 1948	117 18 0		
1950 paid in 1948	4 9 0		
1951 paid in 1948	3 3 0		
	129 9 0		
Publications, 1949	50 12 0		
Postages, 1949	2 16 0		
	53 8 0		
Sundry Creditors for Accounts due but not presented (including provision for printing publications for 1948, not yet completed)		182 17 0	
		2,687 19 10	
			£37,969 0 3

To the Fellows of THE ROYAL ASTRONOMICAL SOCIETY.

We have examined the above Balance Sheet with the Books and Vouchers relating thereto explanations given to us.

We have verified the Securities representing the Investments and have found them to be

SUFFOLK HOUSE,
5 LAURENCE POUNTNEY HILL, LONDON, E.C. 4,
1949 January 27.

1948 *December* 31

	£	s.	d.	£	s.	d.
Investments :—						
General Fund, valued as at 1922 December 29 or subsequent cost...	24,074	11	1			
Trust Funds, valued at cost	6,707	0	3			
(Market Value 1948 December 31, £35,995)				30,781	11	4
Debtors :—						
General	375	11	4			
Income Tax Recoverable :						
General Fund	125	4	9			
Trust Funds	19	10	8			
				520	6	9
Stock of Paper, as valued by the Treasurer				200	0	0
Deposits at Savings Banks :—						
General Fund	£5,083	1	6			
Trust Funds	723	0	10			
	5,806	2	4			
Balance on Current Account at Bank and Cash in Hand :—						
General Fund	297	10	0			
Trust Funds	363	9	10			
	660	19	10			
As per Cash Account				6,467	2	2
				£37,969	0	3

Note.—Fellows' Contributions unpaid at 1948 *December* 31 : £531 2*s.* 0*d.* *This amount represents the total of the Suspense Account and is not included in this Balance Sheet.*

and certify it to be correctly drawn up therefrom and in accordance with the information and in order.

SHARP, PARSONS & CO.,
Chartered Accountants.

INVESTMENTS

As at 1948 December 31

General Fund

£2000 Swansea Corporation 3½ per cent Stock.
£6082 14*s.* 8*d.* British Transport 3 per cent Guaranteed Stock, 1978/88.
£640 15*s.* 7*d.* British Transport 3 per cent Guaranteed Stock, 1978/88.
£2400 Gas Light and Coke Co. 3 per cent Consolidated Debenture Stock.*
£2000 Commercial Gas Co. 3 per cent Debenture Stock.*
£496 Consolidated 4 per cent Stock, 1957.
£1035 Agricultural Mortgage Corporation, Ltd., 4½ per cent Debenture Stock, 1961–91.*
£1000 Hull Corporation 4½ per cent Redeemable Stock, 1952–72.
£1167 10*s.* 0*d.* British Electricity 3 per cent Guaranteed Stock, 1968/73.
£700 Birmingham Corporation 3 per cent Inscribed Stock, 1947.
£2280 5*s.* 3*d.* War Loan 3½ per cent Inscribed Stock.
£500 New South Wales 4 per cent Stock, 1942–62.*
£1156 1*s.* 5*d.* Metropolitan Water Board 3 per cent " B " Stock.
£500 National Defence Loan, 1954–58, 3 per cent Bonds.
£500 Savings Bonds 2½ per cent, 1964/67.
£2118 3*s.* 5*d.* Savings Bonds 3 per cent, 1960/1970. (Holding " A ")
£695 16*s.* 0*d.* Conversion Loan 3½ per cent, 1961.
£2239 13*s.* 8*d.* Treasury 2½ per cent Stock, 1975.
£1200 British Electricity 3 per cent Guaranteed Stock, 1968–73.
£683 3*s.* 0*d.* British Electricity 3 per cent Guaranteed Stock, 1968–73.

Trust Funds

£1004 Consolidated 4 per cent Stock, 1957.
£965 Agricultural Mortgage Corporation, Ltd., 4½ per cent Debenture Stock, 1961–91.*
£491 10*s.* 0*d.* War Loan 3½ per cent Inscribed Stock.
£1160 16*s.* 3*d.* War Loan 3½ per cent Inscribed Stock.
£542 18*s.* 2*d.* Savings Bonds 3 per cent, 1960/1970. (Holding " B ")
£1122 19*s.* 6*d.* Savings Bonds 3 per cent, 1960/1970. (Holding " C ")
£1471 4*s.* 0*d.* Savings Bonds 3 per cent, 1955/1965.

* *Taxed at source.*

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift (1836 and 1844): In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were purchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877): C. J. Lambert, Esq., presented to the Society the sum of £500 free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922): The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1867 October 31.

The Grove-Hills Bequest (1922): Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Grove-Hills Fund (1922): In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913 1*s.* 11*d.*, of which £1480 2*s.* 10*d.* has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent, £423 15*s.* 11*d.* War Stock 3½ per cent, and £695 16*s.* Conversion Loan 3½ per cent 1961.

The Lindemann Bequest (1931): A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933) (*see below*).

The Goodridge Bequest (1936): Captain J. J. L. Goodridge, who died 1936 March 13, bequeathed to the Society the sum of £50, free of legacy duty. In 1937 the bequest was invested in £49 0*s.* 4*d.* War Stock 3½ per cent.

The Herbert Spencer Bequest (1936): Herbert Spencer, Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The bequest was finally expended during 1941.

The Lindley Bequest (1937): Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which was received from the Public Trustee in the form of £1156 1*s.* 5*d.* Metropolitan Water Board 3 per cent "B" Stock.

The Stanley Williams Bequest (1939): A. Stanley Williams, Esq., who died 1938 November 21, bequeathed to the Society all his astronomical instruments, books, maps, photographs, manuscripts, etc., together with the sum of £200, free of legacy duty, for the reduction or publication of his observations of variable stars; and also a further sum of £100, free of legacy duty, for the furtherance of astronomy in general or of the Society in particular, in such manner as the Council of the Society may think fit. No expenditure from the fund has been made up to 1948 December 31.

The Plummer Bequest (1946) (*see below*).

The Carder-Davies Bequest (1948): D. Carder-Davies, Esq., bequeathed to the Society the sum of £3000, free of duty and without any condition, other than the expression of a wish that no part be spent on any purpose controlled or suggested by Government. The legacy has been invested in the following way: £1229 11*s.* in British Electricity 3 per cent Guaranteed Stock; £1770 9*s.* in Treasury 2½ per cent Stock, which have been added to the General Funds of the Society.

SPECIAL FUND

The Archdeacon Potter Fund (1933): Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. This legacy was received in 1933, and now stands invested in £300 3½ per cent War Stock, the cash balance of £17 15*s.* 2*d.* being expended on the library in 1934. The Council resolved to allocate the dividends from this fund for the purposes of the library.

	£	*s.*	*d.*		£	*s.*	*d.*
1948 Jan. 1. Balance of Fund...	18	17	11	1948. Purchase of Books ...	9	1	8
1948. Dividends, War Stock 3½ per cent	10	10	0	1948 Dec. 31. Balance of Fund...	20	6	3
	£29	7	11		£29	7	11

TRUST FUNDS

The Lee and Janson Fund (1834 and 1879): In 1834 John Lee, Esq., LL.D., gave £100, and in 1879 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £309 16*s.* 3 per cent Savings Bonds, 1960/1970.

	£	*s.*	*d.*		£	*s.*	*d.*
1948 Jan. 1. Balance of Fund ...	80	9	8	1948 Dec. 31. Balance of Fund :—			
1948. Dividends, 3 per cent Savings Bonds	9	6	0	In P.O. Savings Bank £39 7 2			
Interest on P.O. Savings Bank Deposit	0	19	0	At Bank 51 7 6			
					90	14	8
	£90	14	8		£90	14	8

The Turnor Fund and the Horrocks Memorial Fund (1853 and 1876): In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £430 10*s.* 4*d.* 3 per cent Savings Bonds, 1960/1970. In 1876 the Society received a sum of £38 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks: to this the Society added the sum of £55 15*s.*, and the whole now stands in £95 13*s.* 2*d.* 3 per cent Savings Bonds, 1960/1970. The interest on these funds is to be used in the purchase of books for the library.

	£	*s.*	*d.*		£	*s.*	*d.*
1948 Jan. 1. Balance of Fund ...	11	16	2	1948. Purchase of Books ...	23	8	6
1948. Dividends, 3 per cent Savings Bonds	15	15	8	1948 Dec. 31. Balance of Fund...	4	3	4
	£27	11	10		£27	11	10

The Hannah Jackson (*née Gwilt*) *Fund* (1861): In 1861 Mrs Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £287 3 per cent Savings Bonds, 1960/1970; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	*s.*	*d.*		£.	*s.*	*d.*
1948 Jan. 1. Balance of Fund ...	21	16	3	1948 Dec. 31. Balance of Fund...	30	8	3
1948. Dividends, 3 per cent Savings Bonds	8	12	0				
	£30	8	3		£30	8	3

The Harry Watson Memorial Fund (1923): In 1920 Mrs Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542 18*s.* 2*d.* 3 per cent Savings Bonds, 1960/1970. In 1923 Mrs Watson bequeathed a further sum of £958 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The*

Harry Watson Memorial Fund, to be used for the purchase and binding of books.

	£	s.	d.		£	s.	d.
1948 Jan. 1. Balance of Fund...	463	16	0	1948. Purchase of Books ...	104	16	11
1948. Dividends, Agricultural Mortgage 4½ per cent ...	23	17	10	1948 Dec. 31. Balance of Fund:— In P.O. Savings Bank £251 15 4			
Dividends, 3 per cent Savings Bonds	16	5	8	At Bank... ... 173 0 11			
Income Tax, 1947 April–1948 April, refunded	19	10	8		424	16	3
Interest on P.O. Savings Bank Deposit	6	3	0				
	£529	13	2		£529	13	2

The George Darwin Lectureship Fund (1926): In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	s.	d.		£	s.	d.
1948 Jan. 1. Balance of Fund...	127	17	8	1948 April. Lecture Fee ...	50	0	0
1948. Dividends, Consolidated 4 per cent Loan	40	3	2	1948 Dec. 31. Balance of Fund:— In P.O. Savings Bank £139 15 7			
Interest on P.O. Savings Bank Deposit	3	8	0	*Less*: Temporary advance from "C" account 18 6 9			
					121	8	10
	£171	8	10		£171	8	10

The A. G. Stillhamer Trust (1937): A. G. Stillhamer, Esq., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually* to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research. The bequest has been invested in £491 10*s*. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1948 Jan. 1. Balance of Fund...	184	5	4	1948 Dec. 31. Balance of Fund:— In P.O. Savings Bank £105 6 10			
1948. Dividends, War Stock 3½ per cent	17	4	0	At Bank... ... 98 14 0			
Interest on P.O. Savings Bank Deposit	2	11	6		204	0	10
	£204	0	10		£204	0	10

* Miss Capps, subsequently to the initial conditions of the Trust, agreed to the income not being expended annually.

The E. W. Brown Trust (1939): E. W. Brown, Esq., M.A., Sc.D., F.R.S., who died in 1938, bequeathed to the Society the sum of five thousand dollars, and desired that the income from the bequest should be used for assistance in the calculation of accurate orbits of the bodies of the solar system, such income as should not be used for this purpose being used for the general purposes of the Society. The bequest was received in 1939 July, and was invested in £1160 16*s.* 3*d.* War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1948 Jan. 1. Balance of Fund...	367	0	9	1948 Dec. 31. To General Funds of R.A.S. Balance of Fund:—	250	0	0
1948. Dividends, War Stock 3½ per cent	40	12	6	In P.O. Savings Bank £186 5 6			
Interest on P.O. Savings Bank Deposit	4	11	0	*Less* : Temporary advance from "C" Account 24 1 3			
					162	4	3
	£412	4	3		£412	4	3

The Plummer Bequest (1946): H. C. Plummer, Esq., M.A., F.R.S., bequeathed to the Society the sum of £1000, to be invested and treated as a Trust Fund, the income to be at the disposal of the Council for all purposes, with a recommendation that they should consider the possibility from time to time of helping the Norman Lockyer Observatory. The Society was also named as one of the residuary legatees. In 1947 October, a first distribution, under the terms of the will, of £1500 was received from the Administrators of the Estate, which has been invested in £1471 4*s.* 0*d.* 3 per cent Savings Bonds, 1955/1965; this sum and any subsequent sum or sums which may be received from the Administrators will be used in accordance with the late Professor Plummer's wishes.

	£	s.	d.		£	s.	d.
1948. Dividends, 3 per cent Savings Bonds	34	4	1	1948 Dec. 31. Balance of Fund.	44	2	8
Income Tax, 1947 April–1948 April, refunded	9	18	7				
	£44	2	8		£44	2	8

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE PRESENTED GIFTS (OTHER THAN BY EXCHANGE) TO THE LIBRARY DURING THE YEAR 1948

H.M. Air Ministry
Astronomical Society of Mexico
Astronomical Society of South Africa
Astronomical Society of Tasmania
Board of Trade, Technical Information and Documents Unit
British Council
British Interplanetary Society
Chinese Geophysical Society
Chinese Physical Society
Copenhagen, Nordisk Astronomisk Selskab
Erevan, Astronomical Observatory

Geological Society of London
German Hydrographic Institute
Ghent, Sterrenkundig Instituut der Universiteit
Griffith Observatory, Los Angeles
Harvard University Committee on Geophysical Research
Imperial Chemical Industries
International Astronomical Union
Lima, Sociedad do Ingenieros del Peru
Lisbon, Sindicato Nacional dos Engenheiros Geografos
London, Institute of Physics
Lourenço Marques, Technical Statistical Department
Manila Observatory, Philippines
National Physical Laboratory
H.M. Nautical Almanac Office
New York, Academy of Sciences
Princeton University
Rome, Reale Accademia d'Italia
Royal Society
Royal Society of Arts
San Miguel, Observatorio de Fisica Cosmica
Sproul Observatory
Service de Prévision Ionosphèrique Marine
Union Radio Scientifique Internationale
United Nations Educational, Scientific and Cultural Organization
Washington, Carnegie Institution
Washington, National Bureau of Standards

Dr A. Armitage
Professor T. Banachiewicz
Professor F. Becker
Mr F. Birch
Dr G. L. Camm
Dr S. Chandrasekhar
Dr L. J. Comrie
The Rev. Dr M. Davidson
Mr P. Doig
Dr A. Giao
Dr P. Guthnick
Dr W. W. Heinrich
Dr J. Houtgast
Professor Harold Jeffreys
Dr M. Kamienski
Mr M. A. R. Khan
Dr Hans Kienle
Dr J. C. Luplan
Dr G. Merton
Professor E. A. Milne
Dr H. Mineur
Professor M. G. J. Minnaert
Dr S. A. Mitchell
Dr A. Pannekoek
Rev. A. L. Parson
Mr R. Paxtot i Jubert
Dr J. G. Porter
Mr D. H. Sadler
Dr D. J. Schove
Mr J. B. Sidgwick
Professor E. Zinner

OBITUARY NOTICES

HENRI ALEXANDRE DESLANDRES was born in Paris on 1853 July 24. Educated at the Ecole Polytechnique he joined the French Army and rose to the rank of Captain in the Engineers before he retired in 1881 : all his life he retained evidence in his bearing of his earlier military career. On leaving the Army he turned his attention to spectroscopy and his first publication in the *Comptes Rendus*, 1884, was a study by means of absorption spectra of the body produced by the action of ozone on paraffin. He then turned his attention to the laws governing the bands in molecular spectra. Alexander Herschel had found that the wave-numbers or frequencies of the lines in the green band of the spectrum of carbon monoxide were in arithmetical progression; Deslandres confirmed this result for a number of other bands at the negative pole of gas tubes at ordinary pressure and extended the observations to cover bands of doublets and triplets with their repetitions of groups of lines similarly related. His next step was to discover that the separate heads of bands of the same molecule were also in A.P., so that the frequencies of a composite band were given by

$$\nu = Am^2 + Bn^2 + C,$$

where m, n are integers. This was called, by Kayser, Deslandres' Third Law. Later, finding that for different series into which the heads of the second nitrogen group had been arranged, the constant C gave a series of numbers such that their squares were also in A.P., he wrote the formula

$$\nu = f(n^2, p^2)m^2 + Bn^2 - \sqrt{(Cp^2 + d)},$$

where p, m, n are integers.

In 1889 on appointment by Admiral Mouchez as assistant astronomer at the Paris Observatory, he abandoned for a time his work on molecular spectra and turned to the organization of the spectroscopic work for the large telescope of the Observatory. He secured the first accurate spectroscopic measure of the velocity of rotation of Jupiter, established the retrograde rotation of Uranus, and carried out some early work on the radial velocities of stars and on cometary spectra. He identified bands due to hydrocarbons and cyanogen in the heads of Comet Daniels (1907) and Comet Morehouse (1908) and bands due to nitrogen at low pressure in their tails.

Meanwhile he had started on researches in solar physics, which were to bring him in due course to a leading position in the astronomical world. Almost simultaneously with Hale he attacked the problem of replacing by photographic means the laborious methods of drawing the forms of prominences from visual observation : both he and Hale discovered in 1891 the reversal of H and K on the Sun's disk as well as on the limb. Deslandres suggested studying the velocity of the gases, a task which led to his developing his *spectro-enregistreur des vitesses*. The wide second slit of this instrument enables the velocity in the line of sight of the gases giving the bright reversals to be measured, so that information can be gathered from it that was not given by Hale's spectroheliograph with its narrow second slit. But Deslandres contributed largely to the development of this

instrument also and later to its application to the study of different levels in the solar atmosphere.

Lack of funds delayed the instrumental work that Deslandres had in mind and it was not until after his return from an eclipse expedition to Fundioum in Senegal in 1893 that he was able to build his *spectro-enregistreur des vitesses*, obtaining his first spectroheliogram in 1894 April. In Senegal he made the first attempt to measure the rotation of the corona and he extended further into the ultra-violet the known spectrum of the corona and of the chromosphere. Other eclipse expeditions that he made were to Yezo in 1896, Spain in 1900 and in 1905. For the second only of these three did he have favourable weather and in addition to repeating earlier observations he measured the total radiation from the corona.

Meanwhile he had been appointed in 1898 to be astronomer at the Astrophysical Observatory at Meudon, where he became Assistant Director in 1906 and, on the death of Janssen in 1907 December, Director. There he re-equipped the observatory, completing the new installation in 1908; already in 1904, with a second slit to his spectroheliograph, 0·03 inch wide, he had isolated the central component K3 of the K line on the Sun's disk. From 1908 onwards with Dr L. d'Azambuja, and with greatly improved equipment, Deslandres produced beautiful results in the study of the Sun's surface in different radiations. Volume IV of the *Annals of the Meudon Observatory* (1911), with its beautiful reproductions, gives clear evidence of the value of the Meudon instruments and observers. Mention must here be made of the work on the dark filaments and on the circulation of the solar atmosphere. The relation between sunspots and terrestrial magnetism was discussed in 1903, when Deslandres made a plea for a continuous record of solar phenomena. The general magnetic field of the Sun was estimated in 1913 as 10^{-7} gauss from the rotation in filaments regarded as helices with axes parallel to the lines of force of the field. Deslandres' model of the chromosphere at this stage was one of alternate layers with electric fields of opposite sign having also magnetic fields of opposite sign. It remains to be seen whether his earlier theories may yet have application to the recent observations of solar phenomena obtained with ciné-camera technique.

Deslandres had been elected to the French Académie des Sciences in 1902 in succession to Faye, had become Associate of the Royal Astronomical Society in 1904 and was awarded the Gold Medal of the Society in 1913 for his " Investigation of Solar Phenomena and other Spectroscopic Work ". He had not abandoned his work on band spectra; among points which he investigated being the different behaviour of bands at the negative and positive poles of cathode-ray tubes and the varying behaviour of bands in magnetic fields of high intensity (30,000 gauss). Certain anomalous results of displacement instead of doubling he explained in terms of component series of small separation and of different intensity.

In the first World War Deslandres was mobilized as a Colonel in the Engineers and he was actively concerned with investigations and experiments on armaments, especially in the design of a " *canon d'accompagnement* ", which proved of great value. He also studied the effect of heavy bombardment on rainfall.

He wrote an interesting " Résumé de Physique solaire " in the *Annuaire du Bureau des Longitudes* in 1919. In 1920 he became President of the Académie des Sciences and in 1921 he was elected a Foreign Member of the Royal Society. In 1920 he continued the earlier work of Schwarzschild in photographing the

component K2 in the spectrum of Arcturus and in a number of other stars of type K, while in 1921 he obtained the component K3 in ε Geminorum and other stars. His attention now turned to the nature of the radiations leaving the Sun, which were linked with aurorae and magnetic storms. He came to the conclusion that there were special disturbed regions on the Sun, points of corpuscular emission arranged regularly over the Sun's surface and working at different depths, the strongest ejection coming from the lowest levels. The 27-day period due to individual disturbed areas is generally recognized but the regular distribution of these areas over the Sun's surface has not been confirmed.

In 1927 Deslandres was made Director of the Paris Observatory as well as of Meudon and he retained the double post until he retired in 1929. He continued his interest in the work of his younger colleagues. As long ago as 1893 he had written about the possibility of studying the solar corona without a total eclipse; in 1923 he had urged the need of a high altitude observatory for France and in 1930 he welcomed Lyot's work on the study of the solar corona without a total eclipse. In his retirement Deslandres returned to the study of spectra and identified a new fundamental unit which, as he claimed, played an important part in the build-up of many molecular spectra and in the Raman effect. Though in the last eighteen years of a long life he wrote a number of papers based on this theory, it cannot be said that he convinced his fellow workers of its success. The last paper that he presented to the Académie des Sciences on 1947 July 16, he described as follows : " La dernière de la longue série de Notes qui depuis 1929 sont consacrées aux relations simples qui unissent la composition chimique exacte de la molécule à son spectre Raman et qui ont conduit aux quatre lois des fréquences moléculaires ", and he added :

" L'étude des molécules est actuellement abandonnée parceque les données experimentales sont trop souvent insuffisantes. Mais leur étude sera reprise lorsque les fréquences Raman seront mesurées avec une précision plus grande et lorsque l'étude chimique des protides et des protéides aura fait des progrès notables ".

Thus wrote the brave old soldier eight days before his 94th birthday. He died on 1948 January 15.

One more aspect of Deslandres' career must be described—his international contacts. He represented the Société Astronomique de France at the First Conference on Solar Research at St. Louis in 1904. He was present at the first conference of the International Union for Cooperation in Solar Research at Oxford in 1908 and was appointed to its committees on cooperation in solar research with the spectroheliograph, on the spectra of sunspots and on solar rotation. At this meeting he presented two papers on nomenclature and on the position of solar research and the means of improving it. At Meudon in 1907 he represented the above-named Société and the Académie des Sciences, as also at Mt. Wilson in 1911.

He did not attend the meeting at Bonn in 1913 but was present at Brussels in 1919 as a delegate from the Académie des Sciences for the foundation of the International Research Council and the International Astronomical Union. He attended the meeting of the Council at Brussels in 1922 and of its successor the International Council of Scientific Unions, also at Brussels in 1934. He was Vice-President of the International Astronomical Union from 1922 to 1928 and attended the conferences at Rome (1922), Cambridge (1925), Leiden (1928),

Paris (1935) and Stockholm (1938). He served on its committees on solar atmosphere, solar radiation, stellar radial velocities, stellar classification, lunar nomenclature, longitudes by wireless and time. The writer well remembers seeing him give a cordial welcome to the German astronomers as they arrived to attend the Union at Paris in 1935.

F. J. M. STRATTON.

LEON HERRERO Y GARCIA, formerly Director of the San Fernando Observatory, died on 1947 June 3. Born at Soria in 1862, he was destined for a career in the Spanish Navy. In 1882 he entered the Military Naval School, at that time installed on the frigate *Asturias*. Until 1891 he followed a normal naval career, serving successively in the Philippines, in home waters and in Cuba; on several occasions he took part in actions against the insurgents of the first Cuban war.

Having shown an interest in hydrographic matters he was sent in 1891 September to the Ecole d'Etudes Supérieures, where he took the special courses in hydrography; in 1894 he was appointed Hydrographic Engineer. He took part in various hydrographic operations in Spanish and Colonial waters, and was awarded the White Cross for Naval Merit. In 1898 he became Naval Instructor in the Military Naval School, a post which he held with distinction until 1906; many of the present senior officers of the Spanish Navy were instructed by him.

In 1906 December he became chief of the Metropolitan Hydrographic Commission. In the *Urania* he took part in various hydrographic surveys, and under his direction charts of the coasts of Galicia and Cantabria were prepared. In 1914 he was appointed an Instructor at the Hydrographic School, of which he became Director in 1915. In 1918 he was promoted Captain and in 1921 was appointed Director of the Naval Institute and Observatory at San Fernando, a post which he held until his retirement in 1940. In 1927 the Hydrographic Service was transferred from Madrid to the San Fernando Observatory and Herrero then assumed the direction of this service, in addition to that of the San Fernando Observatory. In 1931 he was promoted to the rank of Rear-Admiral. Under Herrero's direction, the *Tolfino* and the *Malaspina*, the first Spanish ships to be designed specially for hydrographic surveying, were constructed.

The principal work of the San Fernando Observatory consisted in the preparation of the *Almanaque Nautico* and participation in the Carte-du-Ciel programme. The Observatory shares in the basic computations for the preparation of the national ephemerides, being responsible for the computation of the apparent places of a number of stars. Herrero was a member of Commissions 4 (Ephemerides) and 23 (Carte-du-Ciel) of the International Astronomical Union, and attended the General Assembly of the Union in Leiden in 1928. He was in advance of his time in favouring an International Nautical Almanac. Under his direction, the San Fernando share of the Carte-du-Ciel programme ($-3°$ to $-9°$), which was much in arrears when he became Director, was vigorously pushed ahead and the catalogues of rectangular coordinates for the whole of the zones were completed by 1920 and published. Considerable progress was also made in the publication of the charts.

Herrero was a member of the International Commission for Research of the Mediterranean (Maritime Meteorological Commission) and attended the meetings held in Paris in 1923 and in Malaya in 1929. He was Vice-President of the Oceanographic Section of the International Exhibition in Seville in 1929. He participated in the conferences of the International Hydrographic Bureau in 1926 and 1928 and was a member of the Polar Year Commission.

In 1892 Herrero married Francisca Rodriguez, by whom he had three sons and three daughters. He was elected an Associate of the Society 1928 June 8.

H. SPENCER JONES.

DAVID CARDER-DAVIES was born 1875 March in Kingswinford, Staffordshire (where his grandfather had founded a Pottery, still existent) but left there in infancy, and for most of his life he lived in North London. He had an ailing childhood and was sent to private schools. Before he was eleven he was crippled with rheumatism, and for three months could not walk. A year later his sight failed, for a time wholly. Recovery was slow and partial. His hearing was now impaired and before the age of sixteen he became wholly deaf and so remained. For long his only companions were books, but his wife (he married in 1901) brought him to a more normal life and before her death she accompanied him to Meetings of the Royal Astronomical Society. In 1926 he again became a solitary, with long wanderings and a love for the solitude of sea life in cargo ships. He visited many Pacific islands; his greatest memory being the Marquesas. He was a member of the 1932 Royal Astronomical Society party that visited the Observatories of Canada and United States of America, and with another Fellow, Mr W. H. White, flew over the Grand Canyon. He was drawn to astronomy before his blindness, though defective sight barred serious observation, and he owned several refractors, the largest a $4\frac{1}{2}$-inch equatorial. Microscopy also attracted him but books were his life's main interest, and he had about him a chosen library of some 5000 volumes.

He had no children, and willed his estate to the National Trust, with a legacy to the Society. He was elected a Fellow 1923 April, and was a life Fellow also of the Royal Geographical Society.

GEORGE JAMES GIBBS was born in London in 1866 and upon his family moving to Bedford, about 1874, received his early education at Bedford Modern School, where he was head boy. His mechanical bent being well developed, he proceeded with a scholarship to the City and Guilds Institute, London, where he again distinguished himself whilst studying for his professional career. During this time, and indeed from his early youth, he displayed a love of astronomy which was a source of joy to him throughout life, and which he was ever willing to share with others.

After qualifying professionally, he visited Holland to take charge of work his employers had in progress there before entering business in Accrington and, finally, as a Consulting Engineer at Preston. It is typical of his thoroughness that at the commencement of his stay in Preston he joined the Preston Scientific Society and by his efforts did much to promote its steady growth, being an active Chairman of the Astronomical and Physical Section for several years and President of the Society from 1919 to 1926.

" G. J. G.", as he was affectionately known, not only encouraged astronomical studies by his many lectures and demonstrations, but also took an active part in observations with his own instruments (notably a fine 4-inch refractor by Dancer) and in addition acted as Honorary Curator of the Preston Municipal Observatory. This post he worthily held from 1910 until his sudden death on 1947 February 22.

During his Curatorship, he devoted an incalculable amount of time to the service of the public, willingly sacrificing his own interests in order to foster in others the enthusiasm which never deserted him. Despite the great demands made upon him for professional services (he specialized in hydraulic engineering and became an acknowledged expert) he was never too busy to help the novice, and but for this self-effacement would doubtless have attained more prominence in astronomical circles. As it was, he contributed several communications to our Society and also was in 1914 appointed a member of the Society's eclipse expedition to Hernösand, Sweden.

His most prominent work in astronomy, however, was the inception of the new municipal Jeremiah Horrocks Observatory, Preston, which was essentially his creation from the drawing of the plans to the performance of routine observations with the 8-inch refractor. Here, with characteristically neat illustrations, he gave lessons to numerous adults and school children and in doing so must have encouraged many to become life-long students of the science.

The pleasant recollections of his courteous manner, kindly teachings and the institutions he has left are memorials to a true amateur of science, whose exceptional talents enabled him to be also a fine musician and skilful artist.

His wife Annie (*née* Thomlinson) was a native of Bedford and taught for many years in the Girls' Modern School there. She died in November 1936. He is now survived by his daughter whose great loss is best realized by those privileged to have known him.

He was elected a Fellow of the Society on 1912 January 12.

F. HOLDEN.

ALGERNON CHARLES GIFFORD died at his home at Silverstream, Wellington, New Zealand, after a fairly long illness, on 1948 February 27. With his passing, New Zealand lost its most enthusiastic and inspiring astronomer, as well as the last of a strong team. Sommerville, as Professor of Mathematics, Adams, as Government Astronomer, Gifford as the exponent of astrophysics and Ward as telescope maker and observer, combined to make a team which may well be said to have established whatever astronomical foundation this small country, just past the pioneering stage, possesses.

Gifford was born on Good Friday, 1861, in the ship *Zealandia*, somewhere off the Cape of Good Hope. His father, a Church of England minister, was on his way out to take charge of the parish of Waitaki. After receiving his primary education at Oamaru Grammar School he was sent back to England in 1876, where he attended Denstone College and gained a sizarship to St. John's College, Cambridge. Here he took his M.A. degree, and in 1880 graduated fourteenth Wrangler and won the Herschel Prize in astronomical mathematics.

Returning to New Zealand, his qualifications in science and mathematics placed him in those departments in the Waitaki High School (1883–89), Christ's College, Christchurch (1889–92) and Wellington College (1895–1927), where he was acting principal for a period. He came to be known all over the country, with

affection, as " Uncle Charlie "—a title of honour and respect. From 1927 to the time of his death, he spent a retirement filled to the brim with activity. As a gardener on a scale which would have deterred most young men, an amateur astronomer and with an extremely live interest on the question of the authorship of Shakespeare and economic questions of the day, he was never idle. He married the daughter of the late Hon. George Jones, proprietor of two South Island newspapers and remembered as the man who once challenged the Parliament of New Zealand. Besides his wife, he is survived by three sons and two daughters.

In his early days he was a keen geologist, pursuing his subject in the field and exerting himself in extensive explorations of little-known areas. Even at the age of 65 he climbed Mt. Ruapehu, and it was on one such trip that he suffered heartstrain through overloading, although this was not the cause of his death.

The name Gifford will always be linked with Bickerton, and the theory of partial impact for the origin of novae and the solar system should be labelled the Bickerton-Gifford Theory. Bickerton, with whom Gifford came in contact in Christchurch, supplied the general idea, and Gifford polished it to a state where it might receive some consideration. Gifford was by no means unaware of the failings of Bickerton, but he had an intense admiration for the old professor, and collected all his manuscripts, printed papers and documents. With an enthusiasm of almost religous fervour, Gifford would propound the partial impact theory in such a manner that one felt, having known him, one also knew to some degree Bickerton.

While at the present stage of astronomical knowledge one might not feel disposed to give the partial impact theory of novae more than a passing notice of probability, the theory as applied to the origin of the solar system has not had the recognition or consideration it deserves. Rather provocatively, Gifford pointed out how Jeans initially considered collisions between stars to be so rare that they may be disregarded, and then later when dealing with the origin of the solar system had a passing star coming so close to the Sun, that he acknowledged the limit was not much greater than the distance at which physical collision takes place. That insufficient notice has been taken of Gifford's work in this respect may be due in part to the fact that most of his work was written in semi-popular style, without mathematical analysis. Although not a practical observer, in the usual sense of the term, observational data were of the utmost importance to him, and he treated with scorn " the great show of mathematics " or the " manipulation of mathematical equations " to obtain results which to him seemed to have no physical meaning. Being of the classical science school, he himself could produce such remarkable results from elementary mathematics, that most of his audiences felt there must be a " catch " somewhere. Some unpublished papers, if worked up, may place his theory of the origin of the solar system on a firmer foundation.

He pushed all aspects of impact to their limit, even considering the impact of spirals. The meteoric theory of the origin of lunar craters found in him a staunch champion. His later work was concerned in studying and trying to explain Sulaiman's theories.

Because of the drift of astronomical thought in other directions, and the apparent neglect of his own work by astronomers, there is no doubt that Gifford at times felt lonely. His ideas began to take on the appearance of being unorthodox, and later he somewhat prided himself in being unorthodox, not only in

astronomy, but also in his other hobbies of the authorship of Shakespeare and economic suggestions. Above all, he was a rugged individualist.

Apart from his theories and technical lectures to Universities and scientific societies, Gifford will always be remembered in New Zealand as the great peer of popular writing and lecturing. When bound into booklet form, his newspaper articles, " In Starry Skies ", make one of the finest elementary textbooks available, and it is a pity that they were not produced in proper book form after careful arrangement. As a lecturer he could be guaranteed to fill the largest halls in Wellington and keep his audience enthralled for two hours or more; and he would lecture anywhere, to schools, clubs, or the general public, no matter how inconvenient it might have been for him.

Charles Algernon Gifford was a member of all the major astronomical societies : The Royal Astronomical Society, the British Astronomical Association, the Astronomical Society of France, the Royal Astronomical Society of Canada, and the Astronomical Society of the Pacific. He was a past president of the Royal Astronomical Society of New Zealand and a pioneer of the Wellington Philosophical Society in its early years. He established the Wellington College Observatory, containing a 5-inch Zeiss refractor and at one time had the title of Associate of the Dominion Observatory, Wellington.

He was elected to the Society on 1915 January 8.

I. L. THOMSEN.

RICHARD FRANCIS TURNEY GRANGER was born at Nottingham on 1900 February 7. He was educated at Rugby and became in time a Director of R. Granger and Sons, Lace Manufacturers, of Long Eaton.

It was the daylight comet of 1910 that fired his interest in Astronomy and on leaving Rugby a 12-inch reflector was on loan to him from his school for several years. His main scientific interest, however, next turned to Meteorology and in 1921 he read a paper on " The Physical Structure of Cloud Form in the Lower Atmosphere " before the Royal Meteorological Society, of which he was a Fellow. Considering that further research would necessitate flying he started to design his own aeroplane and by 1930, with the help of his brother, built and put into the air not merely an aeroplane but a tailless aircraft. That the design was almost identical with that of the latest German jet-fighter in the recent war shows that his ideas were well ahead of the times. He retained his interest in cloud formations to the end.

Astronomical activity revived in 1935 when an observatory with a 6-inch reflector was built, followed by the construction of a 10-inch reflector. He joined the British Astronomical Association and became a member of its Variable Star Section to which he contributed most promising observations.

On the outbreak of war he volunteered for the Royal Air Force but owing to age was debarred from operational flying and served as flying-instructor and later as test-pilot at the Royal Aircraft Establishment. On an experimental flight undertaken for meteorological reasons he had a serious crash and it was as a result of injuries then received that he eventually died on 1948 January 19.

After demobilization he had brought his observing equipment into first-class condition and was hoping to embark on photometric and other studies in spite of certain disabilities forced on him by his accident ; there is little doubt that

valuable results would have accrued. Climbing, music too, and painting claimed a part of his time.

It is hard to believe that anyone who ever met him can have failed to sense his restless energy, finely-tempered intelligence and soaring personality.

He leaves a widow and two children.

He was elected a Fellow of the Society on 1940 June 14.

W. M. LINDLEY.

JOHN JOHNSTON ROSS died in Glasgow on 1948 May 27 at the age of 73. He was a son of Dr David Ross of the Normal Training College for Teachers in Glasgow; educated at the High School and at the University, he graduated M.A. in due course. He was also a B.A. of London University.

Ross spent his active life on the administrative staff of the Education Department of his native city, bringing into his work a genuine enthusiasm for the cause of education and learning. During all his adult life he was keenly interested in astronomy and for many years he acted as astronomical correspondent of the "Glasgow Herald", in which capacity he showed a marked gift for describing the salient features of astronomical lectures and for interesting the lay public in the principal scientific topics of the day. He was a life-long member of the West of Scotland (later, the Scottish) Branch of the British Astronomical Association, serving for many years as Secretary, later as President, and almost continuously on the Council.

Ross was unmarried and is survived by a younger brother, Alexander D. Ross, Professor of Mathematics and Physics in the University of Western Australia.

He was elected a Fellow on 1920 February 13.

W. M. SMART.

JAMES PETER ROWLAND was born at Blackburn on 1875 June 29, and spent his early years at Woodfields, within sight of the Observatory with which he was to be so closely associated. He joined the Society of Jesus in 1894, and in addition to his philosophical and theological studies took a B.Sc. degree at London University in 1906. After his ordination he taught Mathematics and Physics for a number of years in Jesuit Colleges, and was responsible during this time for the designing of the School Science Laboratories at Mount St. Mary's College, near Sheffield, where he had himself been a pupil.

In 1919 he was appointed Assistant Director of Stonyhurst College Observatory. The remainder of his life was entirely devoted to work at this Observatory, of which he became Director in 1932. During the period of his Directorship, he maintained, under ever-increasing limitations of staff, the full programme of meteorological, magnetic and seismic measurements, together with the daily solar drawings, and the associated measurement of spot positions and areas. Himself a scrupulously careful and methodical observer, he was responsible for all the magnetic measurements, and the reduction of the seismograph tracings, and such work as he was obliged to depute to others he kept under the strictest supervision. In 1936 he redetermined from stellar observations the azimuth of the reference point used for the magnetic observations with the Kew pattern magnetometer, and discovered a long standing error of 2′ in the previously accepted value, which had been based on solar observations. He was thus able

to apply this considerable systematic correction to his predecessors' observations, a fact which one suspects gave him great satisfaction.

Shortly after his appointment as Director, he set to work to overhaul and improve the drive of the 15-inch refractor used for the solar drawings. This was no easy task, since the equatorial mount had originally been designed for an 8-inch telescope. His notable photograph of Comet Finsler, taken in 1937 with a short-focus camera mounted on this instrument, is sufficient indication of his success in this task, and of his skill as an observer.

His heavy routine programme left him little time for special researches, but he brought to such as he did undertake the very high standards of reliability which he rightly regarded as a *sine qua non* of useful scientific work. One may instance as an example of his approach, his careful paper on the determination at Stonyhurst of the rotation period of Saturn from observations of the spot discovered by Hay in 1933. He departed from the more customary method of estimating from a single observation the time at which the spot reaches the mid-point of its transit. Instead, he used the expedient, suggested by his solar work, of measuring the position of the spot on the disk during the whole period of transit by means of a moving-wire micrometer. In this way he greatly reduced his random error. His determined period was $10^h\ 14^m{\cdot}14$, a slightly shorter value than the period of $10^h\ 14^m{\cdot}947$ calculated subsequently by Peek from an analysis of all available measures of the spot.

To his love for the fundamental techniques of simple measurement, Father Rowland added a great mechanical skill and a rare knowledge of laboratory arts. The writer remembers once admiring a frame of fine cross-wire fibres at the Observatory, and asking Father Rowland how he had come by them. His answer began, " You must first catch your spider . . . ."

By nature a man of a shy disposition, Father Rowland led a secluded life, totally absorbed in his scientific labours. Yet his weather forecasts and occasional announcements of earthquakes brought him before the public eye. Indeed, his name had become somewhat of a legend among the ordinary people of Lancashire, a fact of which he was perfectly well aware. Yet he was never disposed to exploit this popular esteem, and showed in his newspaper announcements the same reticence and unwillingness to go beyond his observations that characterize his whole work.

Father Rowland was elected a Fellow on 1921 January 14. He retired from the Directorship of Stonyhurst Observatory when work there was suspended at the end of 1947. His death occurred on 1948 December 26, after a short illness.

P. J. TREANOR.

JOHN JOHNSON SHAW was born at Gornal, near Dudley, and he died at West Bromwich 1948 May 23, at the age of 74 years, following an operation for the amputation of a leg.

To seismologists the world over, Shaw's name is familiar through his development of the Milne-Shaw seismograph. This instrument is a horizontal pendulum, and represents a great advance on the early Milne type of recorder. It has a long achievement of good work, thanks to its reliability and simplicity of operation, and it represents the fruits of a friendship with John Milne that began in 1908, not long after the latter had returned from Japan and established an

observatory at Shide, near Newport, Isle of Wight. In 1920 Shaw made observations of microseisms with similar instruments situated two miles apart; this work was of fundamental importance, and from it arose his suggestion of a tripartite installation, with instruments at the three corners of a right-angled triangle, a suggestion unfortunately not carried out then for want of funds. In recent years this line of attack has led to important developments, notably in U.S.A.

As a seismologist, Shaw remained an amateur, and an amateur in the best sense of the word. An engineer by training, by profession he became a pawnbroker, and the West Bromwich seismological station was in fact situated in his own home. His popular lectures, and his readiness to give the Press his preliminary estimate of the epicentral region of any large earthquake recorded by his instruments, were of great service in making widely known the importance of this comparatively young study. For over 30 years (1915 to 1946) he was Secretary of the British Association Seismological Investigations Committee; for much of this time H. H. Turner was Chairman, and the partnership was of great value to British seismology. Shaw was a British delegate to most of the reunions of the International Geodetic and Geophysical Union. He was created C.B.E. in 1931, and in 1932 was given the honorary degree of M.Sc. by the University of Birmingham.

Shaw's genial nature, his devotion to science, and his readiness both to help and to learn made him many friends. He was in harness to the last : in a letter written a few days before his operation to Professor J. B. Macelwane, S.J., St. Louis, Mo., on the subject of microseisms, he referred jestingly to the forthcoming amputation of a leg that had done such good service for so many years. It is hoped that his work at West Bromwich will be continued by his son, Mr H. V. Shaw.

He was elected a Fellow of the Society 1940 January 12.

R. STONELEY.

PROCEEDINGS OF OBSERVATORIES

Royal Observatory, Greenwich

(Director, Sir Harold Spencer Jones, F.R.S., Astronomer Royal)

The move to Herstmonceux remains disappointingly slow, and a large proportion of what it was hoped to achieve during the past year still lies ahead. The Astronomer Royal and Secretariat moved in the summer, and the Chronometer Department in the autumn; the Solar Building is approaching completion, and it is hoped now that this Department will be able to start moving in a few more months.

Meridian Department.—The restricted programme of observations with the Airy transit-circle has continued. During the year, 114 observations of the Sun, 71 of the Moon, 31 of Venus and 41 of other planets were obtained, together with 1156 transit and 938 zenith distance observations of standard stars. The preparation of the first Greenwich Catalogue of stars for 1940 has been further delayed by shortage of staff.

The reversible transit-circle has been the subject of extensive further study. Pivot errors have been determined by an autocollimation method, using a plane mirror mounted on the end of the pivot. The higher harmonics of the pivot errors resemble very closely those obtained by the Airy method before the war; the new method, however, is very much faster indeed, for the same accuracy, and it is proposed to redetermine the pivot errors from time to time, during the life of the instrument. One disturbing feature remains, however; the measurements still show a dependence on the direction of rotation of the instrument. This was present before the war, and in spite of modifications to the end-thrust and to the counterpoising it has not been eliminated.

Observations on the stars of the new Photographic Zenith Tube catalogue were begun on September 21; but further studies of the micrometer, which were undertaken concurrently, showed such grave faults that observational work was broken off again and extensive alterations of the micrometer undertaken. The R.A. wire now appears to be performing satisfactorily; the Z.D. one has been improved, and its performance-error, though it has not yet been eliminated, has been determined; several further modifications have still to be made.

Astrometry and Astrophysics Department.—The 26-inch object-glass was examined in November, the two components being separated. The lens seems not to have suffered from the many moves that the war made necessary.

In view of the serious deterioration of the aluminium coat on the 36-inch mirror it has been decided to revert to the pre-war regime of six-monthly silvering until the telescope is moved to Herstmonceux. The resulting loss of efficiency (for the slit spectrograph is designed for use in the ultra-violet) emphasizes the need for speedy removal.

Measurement and reduction of the Cape wide-angle plates of the dec. zone $-56°$ to $-60°$ have proceeded steadily. Of the zone total (including long-exposure plates) of 113 plates, 106 have now been completely reduced, covering the region between $15^h\ 12^m$ and $13^h\ 04^m$. Standard coordinates have now been computed ahead for the whole zone. Though little of the zone thus remains to be

completed, the region involved comprises a section of the Milky Way, where both computation and measuring are heavy.

Gaps left in the observing list with the Yapp reflector by the completion at certain R.A.s of the programme of photographing the ultra-violet spectra of late-type spectroscopic binaries have been filled by including double exposures on bright late-type and faint early-type stars so as to estimate the sensitivity of the method for detecting hot companions in late-type binaries. In addition, some K0 stars suspected of being intermediate in absolute magnitude between giants and dwarfs have been added to the list, and some preliminary work has been done to assess the suitability of the slit spectrograph for measuring spectrophotometric gradients throughout the spectrum. In all, 176 spectra of 52 stars have been secured.

The vacuum distillation plant has been used for routine coating of several small mirrors in use in the Observatory, as well as for exploratory work on the suitability of different methods of depositing aluminium and other metals or combinations of metals.

Time Department.—Owing to the many unforeseen delays which have occurred in the completion of the photographic zenith telescope, the Greenwich time service is still based on astronomical observations made with small transit instruments. The Bamberg instrument has continued to provide results superior to those obtained previously with the older pattern of small reversible transit. During the period 1948 January 1 to November 30, 292 observations were secured at Abinger and used in the determination of clock error. In the same period, 162 observations were obtained on the small transit instrument at Greenwich.

Control of the Rugby time signals and of the six-pips and hourly signals has been maintained from the main station at Abinger. The daily standard frequency transmissions from Abinger have been continued and are used by an increasing number of establishments. In order to permit frequency comparisons to be made with establishments beyond the service area of these transmissions, daily measures are made, at $10^h\ 30^m$ G.M.T., of the carrier frequency of the B.B.C. transmitter at Droitwich, using a receiver designed in the laboratory. Simultaneous measures at two stations have shown that a very high standard of accuracy of frequency comparison can be obtained in this way.

Further development work on receivers for long-wave radio time signals has been carried out. The variation in the lag of these receivers has been found to be of the order of 0·2 milliseconds. The experience gained is being applied to the construction of a special receiver for use in the Solar Department for the correlation of solar flares and radio phenomena.

By courtesy of the Engineer-in-Chief, Post Office, special time signals were radiated in connection with the Kenya eclipse observations. As these signal series were of longer duration than the normal daily rhythmic series, they provided an opportunity to examine the stability of the delays introduced by the land lines and transmitter. Some deterioration in the transmission conditions has been evident during the last few months, and the eclipse time-signal results showed these effects very clearly. The matter is now receiving attention in cooperation with the Post Office Telegraph Branch.

Optics Laboratory.—Defects in the performance of the driving system for the Photographic Zenith Tube have been removed by suspending the carriage so that all the constraints become entirely elastic. Further substantial improvement of

the drive was obtained by reducing the minification of the differential roller system. Other modifications and simplifications have been made in the design, and construction is now in progress.

Further experimental work in connection with the measuring machine is being carried out with the aid of special graticules constructed in the laboratory. Progress in other aspects of the work has been much impeded by loss of staff.

Solar Department.—The Sun was photographed on 279 days. Up to November 30 there is one day (January 1) unrepresented in the combined series, but a contact plate for this date has been received from the Superintendent, U.S. Naval Observatory, Washington.

The measurement of 301 plates has brought the measures of the combined series to 1946 February 14. Results for 1940, 1941 and 1942 are published in *Monthly Notices* for 1948.

The Sun's disk was observed in $H\alpha$ with the spectrohelioscope on 164 days; on 34 of these, observation was possible only for 15 minutes or less. 213 measures for any small line-of-sight motions were made on normal and flare patches of bright flocculi, most of these measures also giving effective line-widths of $H\alpha$. 321 measures were also made on dark filaments on the disk and 34 measures on limb prominences. Line-of-sight velocities for dark filaments exceeded 100 km./sec. in six cases, the highest value being 180 km./sec. outwards from the Sun on May 7. 173 sets of photometer measures were made collectively on normal bright flocculi and flares.

63 solar flares were observed. The central intensity of one of these (May 21) exceeded twice the intensity of the adjoining continuous spectrum. From the joint occurrence of short-wave radio fadeouts (reported by Cable and Wireless Ltd.) and geomagnetic crochets recorded at Abinger, flares above average intensity occurred on March 20 at $12^h\ 23^m{\cdot}7$ and (by a curious coincidence in time) on April 20 at $12^h\ 23^m$ U.T. Other probable cases were June $21^d\ 07^h\ 45^m$; July $29^d\ 12^h\ 50^m$; November $14^d\ 12^h\ 12^m$, and December $23^d\ 12^h\ 11^m$, all times being those of the onset of the crochet.

Informal liaison has been maintained with the Radio Section of the Cavendish Laboratory, Cambridge, concerning solar flares observed at Greenwich and synchronous radio anomalies recorded at Cambridge in the reception of signals on very long waves.

During the year, the original and duplicate coelostat mirrors of the spectrohelioscope were gilded by evaporation in the vacuum equipment recently acquired by the Royal Observatory. Gold reflects as well as aluminium at $H\alpha$, and the scattered light in the observing room is much less.

Nautical Almanac Office.—Although there has been a general overtaking of arrears of composition and proof-reading for the Office publications, the actual printing and binding are now taking much longer, so that the dates of publication are not being advanced as rapidly as expected. The *Nautical Almanac* for 1950 will not be published until early in 1949, but it is planned to advance the date of publication by about 2–3 months annually.

The serious shortage of senior staff—there are several unfilled vacancies—has again made it impossible to make any substantial progress with the outstanding astronomical investigations. Work on the promised *Supplement* is proceeding very slowly, while there are still disturbing arrears in the occultation programme;

the discussion of the 1943 occultations was published during the year in the *Astronomical Journal*, and those for the years 1944 and 1945 are very nearly complete.

An ephemeris of Pluto will be included in the *Nautical Almanac* from 1950 onwards.

Some changes have had to be made in the allocation of the computations for the volume of *Apparent Places of Fundamental Stars*. For 1950, the Nautical Almanac Office computed the apparent places of 216 stars normally supplied by the Office of the *Connaissance des Temps*, and this arrangement will be continued in future years; the Institute for Theoretical Astronomy in Leningrad has undertaken to supply, from 1951 onwards, the computations for the remaining 210 ten-day stars of the normal Paris allocation.

At the conference of Commonwealth Survey Officers in 1947 August a request was made for a special almanac for the use of surveyors; the Office prepared detailed proposals for a separate *Star Almanac for Land Surveyors* and these have recently been approved. The first issue (in 1950) will be for the year 1951.

Much effort has been expended during the year in discussion of the proposals for the revision of the *Abridged Nautical Almanac*; after detailed consultation by means of lectures, meetings, publications and much correspondence—with all classes of users—the final form of presentation has now been settled. The Almanac will tabulate Greenwich Hour Angle in arc directly, instead of right ascension, which has been used in the navigational almanac since it was introduced in 1767. The new almanac will be issued early in 1951 for the year 1952.

In addition, there have been several special investigations into methods and tables for both sea and air navigation; a comprehensive survey of tables for astronomical polar navigation has been made, and is in course of publication.

The Office continues its responsibilities in regard to the computational work necessary for the latticing of charts required for the Decca system of navigation; in June the Superintendent paid a short visit to the Danish Hydrographic Office in Copenhagen, in connection with the work on the Danish Chain.

After three years' discussion, approval has recently been given for the installation of a complete range of Hollerith punched-card equipment, suitable for general computational work; it will, however, be fully another year before delivery of the actual machines can be made. It is intended to extend the use of the equipment, where suitable, to the work of the Observatory as a whole, as well as to the more routine work of the Office; it is also hoped, eventually, to produce copy for some of the Office publications automatically on card-operated machines.

Eclipse Expedition.—Dr Atkinson and Mr Pope went to Mombasa for the eclipse of 1948 November 1; Mombasa was a little outside the path of totality, and the purpose was to obtain a timed cinema record of the crescent's swing-round in position-angle. Old R.A.F. 35-mm. cameras were used, in conjunction with chronographs that had been built at Abinger, and four 50-foot collapsible radio-masts for the reception of time signals. The Resident Naval Officer was very cooperative and, in addition to providing labour and mechanical assistance, allowed two of his staff to act as assistants for the observations. In this way it was possible to run two stations instead of one. Successful records were obtained, and measurement is about to begin; a micrometer has had to be modified for the purpose.

Royal Observatory, Edinburgh

(*Director, Professor W. M. H. Greaves, F.R.S., Astronomer Royal for Scotland*)

Spectrophotometry.—The study of line intensities of early-type stars of apparent magnitude 5·0 or brighter has been continued. The work of measurement and reduction is now behind the output of plates with the telescope and, in view of this circumstance and of the fact that most of the spectra still required to complete the programme are of the fainter stars requiring comparatively long exposures, work at the telescope has been largely confined to nights for which the observing conditions were good. During 1948, 51 spectra were secured on 29 nights.

The spectrograph has been modified to allow of work being done with any required orientation of the slit. This has involved the provision of mechanism, made by Mr A. Steuart, for widening the spectra by rocking a quartz plate near the slit and between the latter and the collimator lens.

The spectra are measured with a non-recording thermoelectric microphotometer of the Moll type at upwards of one thousand fixed wave-lengths, and the measures for the several negatives of the same star are combined so as to reduce the effect of plate grain and other accidental errors. The reduction of the measures is based on their combination not only for the individual stars but also for all stars of a given spectral type. To determine the curvature of the continuum (arising mainly from variation with wave-length of the sensitivity of the photographic emulsion used) it has been found desirable to use the mean of a group of selected stars of spectral type Oe5, for which the Balmer lines are comparatively narrow, as a standard of reference. The measures for the Oe5 stars have accordingly been reduced first and the results for seven stars of this type are now ready for publication. These will be the prelude to the results for some 100 stars of spectral type B.

The line intensities for the Oe5 stars measured at Edinburgh are, with the exception of the $H\beta$ line, in good agreement with those found by Williams at Mount Wilson, and are considerably lower than those found by Petrie at Victoria. The method of working is especially favourable to the measurement of the absorption near $\lambda 4430$, which appears to have a total breadth of the order of 100 angstroms. The intensity of this "interstellar" absorption in the seven Oe5 stars is found to bear a strong linear correlation to colour or gradient excess and to have little correlation with the intensities of the interstellar D lines.

Solar Work.—The Sun was observed in $H\alpha$ light with the combined spectrohelioscope and spectrograph on 193 days. Accurately oriented disk drawings for sunspots in white light were made on 166 days with a 5-inch image. With the 16-foot spectrograph (dispersion element a 5-inch Rowland grating) 144 calibrated plates of flare and prominence spectra were obtained, and for each of these plates the position of the spectrograph slit was located on one of the disk drawings, together with an outline of the flare or prominence being photographed.

41 flares were observed during the year, classified as follows: 28 Class 1, 12 Class 2 and 1 Class 3. Records of all flares were communicated quarterly to Meudon for inclusion in the *Quarterly Bulletin* and daily records were sent to the Cavendish Laboratory, Cambridge. Arrangements were made to report by telegram flares of exceptional intensity to the Royal Observatory, Greenwich, and to Meudon for inclusion in the B.I.F. broadcasts.

The investigation of the effective line-width, central intensity and symmetry of the $H\alpha$ emission line in flares has been continued and some of these results have

been communicated to the Society. Much time has been spent on determining the corrections to be applied to observed line-profiles on account of grating ghosts and general scattered light in the spectrograph.

Miss M. Conway, a research student, has been working on the $H\alpha$ line-profiles of certain prominence types, both on the disk and at the limb.

Stellar Photometry.—The Star Actinometer, which had been under construction since November 1946 by Messrs P. J. Kipp and Sons, of Delft, was completed in October and delivery was obtained in early November. The instrument was erected and tested during the month following and was brought into use before the end of the year.

The Actinometer is almost a replica of that which was designed on the Moll and Pannekoek system, and also constructed by Messrs Kipp and Sons for the observatory at Groningen. It has been designed to handle plates up to 12 inches by 10 inches and the optical and engineering work are of such precision as to meet the highest demands of stellar magnitude determination. The circular exploring beam of light, after passage through the plate, is received upon the sensitive surface of an Evans rectifier photocell whose currents are measured by means of a Zernike quartz-suspension galvanometer. An interchange of optical parts and the insertion of bi-lateral slits in place of the circular diaphragms enables the instrument to be easily converted into a recording microphotometer of the Moll type for the analysis of objective prism and other spectra. For spectral recording a vacuum thermocouple is employed as the sensitive receiver and this is placed in series with a Moll *Micro* galvanometer.

A small number of plates was taken with the 10-inch Astrographic Camera on stars of the North Polar Sequence. The measurement of these plates was begun with the Actinometer with the object of laying down a magnitude scale and of deriving corrections to be applied to magnitudes determined at various distances off the axis of the lens.

The Astrographic Camera will shortly be removed from its present mounting in the West dome and will be re-erected in the dome on the lawn which formerly housed the 6-inch Cooke refractor. A new mounting for it is being prepared by Messrs Cox, Hargreaves and Thomson. Its place in the West dome will eventually be taken by a Schmidt telescope employing a 24-inch spherical mirror of 60 inches focal length and a 16-inch corrector plate, the contract for the construction of which has also been placed with Messrs Cox, Hargreaves and Thomson.

Staff.—The authorized staff of the Observatory consists of the Astronomer Royal for Scotland, two Principal Scientific Officers, two Scientific Officers, one Senior Assistant (Scientific) and one Assistant (Scientific), a clerk-typist and a porter-messenger. The posts of Scientific Officers, which had previously been vacant, were filled by the appointment of Mr R. Wilson on 1948 September 1 and Mr H. Schneider on 1948 September 13. The post of Assistant (Scientific) is still vacant. The stellar spectrophotometric work is being carried out by Dr Baker, assisted by Mr Wilson; Dr Ellison, assisted by Mr Schneider, is engaged on the photometry with the 10-inch camera and on the solar work.

Visitors.—During 1948 two visits were paid to the Observatory by Professor Jean Martin and members of the *Expédition polaire française*, who made gravity measurements in the clock basement of the Observatory, on the south side of the pier which supports the 36-inch reflector. On October 29 there was a meeting of the Royal Astronomical Society in Edinburgh, and on the morning of that date Fellows were invited to visit the Observatory, and to inspect the instruments and

the results which are being obtained with them. A fuller account of this visit will be found in *The Observatory* for 1948 December.

Royal Observatory, Cape of Good Hope

(*Director, Dr J. Jackson, F.R.S., H.M. Astronomer*)

Reversible Transit Circle.—The observation of standard stars for the zone $-64°$ to $-80°$ is nearing completion, and there are now considerable gaps in the observing programme for stars observed in the summer months. In all, 5977 transits were observed, including 256 stars observed in the daytime and the following observations of bodies of the solar system:—

Sun	165	Mars	15
Moon	21	Jupiter	13
Mercury	45	Saturn	13
Venus	89	Neptune	12

The reductions are well up to date, including the comparisons of the observed and computed places for the Sun, Moon and planets.

A new working programme is being prepared. It contains all the G.C. stars between $-30°$ and $-52°$ and from $-80°$ to the pole. FK 3 stars between $-20°$ and $-30°$ with the usual clock and azimuth stars are also included.

Photographic Zone Observations.—During the year 54 plates were taken to complete the photography to declination $-80°$. In the office most time has been given to work on the zones $-52°$ to $-56°$ and $-60°$ to $-64°$, the plates for the intermediate zone having been sent to Greenwich for measurement. For the zone $-52°$ to $-56°$ the measured residuals are being reduced to give corrections to the preliminary positions and proper motions. Work for the 1270 stars contained in the G.C. has been completed. For the more southerly zone the computation of standard coordinates has been completed, and about half the plates (3500 stars) were measured. Dr Cillié's work in classifying spectra for the zones $-30°$ to $-35°$ and $-35°$ to $-40°$ was completed and the catalogue for these zones will be ready for printing as soon as we decide on the final system of photographic and photovisual magnitudes.

Victoria Telescope.—The telescope was principally used for the observations for determination of stellar parallax. No new stars are being added to the working list—which consists at present of about 360 stars, of which about one-third are important stars being reobserved, one-third rather faint stars of large proper motion from Luyten's and other lists, and the other third miscellaneous stars. 2403 plates were taken on 241 nights. In addition 58 plates were taken for the proper motion of parallax stars.

Measurement of plates continued throughout the year with two machines. 2150 plates were measured and 55 rejected, leaving 10,130 still to be measured. The number of stars for which parallaxes have now been determined is 1572. The number of parallaxes determined during the year was 62, of which 23 were new determinations of stars previously observed.

The determination of the magnitudes of the parallax stars was continued during the first half of the year. Both the 24-inch photographic lens and the 18-inch visual lens are now provided with Fabry units. The plateholder of the 24-inch has been attached to the breech end by a hinge and it is now possible to change the

occulting shutter very rapidly. Also a special device has been fitted so that the timing of the exposure is automatic. In June the 18-inch lens was dismounted and sent to England to be repolished and observations have been discontinued till it is returned. During the first five months of the year 871 observations were made on 38 nights.

Photographic and Photovisual Magnitudes.—While considerable progress has been made with the various programmes outlined in previous annual reports the main effort during 1948 was directed to the problem of setting up accurate standard magnitudes for stars in the nine E regions at declination $-45°$. About a hundred thousand images on various series of plates taken at the Cape and Pretoria were measured with the modified Schilt photometer for this work. These were combined with previous measures to give a set of standard magnitudes on what is described as the southern or S system. The scale of these magnitudes has virtually been determined from observations made at the Cape and Pretoria by the Fabry method with rapidly rotating sectors. It is believed that the scale, zero and colour systems of the S magnitudes is uniform from E region to E region to within $0^m{\cdot}02$ between magnitudes 6·0 and 10·0 photovisual. The relationship of the S system to the International system is not yet known to anything like this accuracy, but it is hoped that a firm link may result from the work now being done at Cambridge with our lenses in comparing Kapteyn Areas at $+15°$ with the North Pole.

In order to ensure the widest possible choice of suitable standard stars for future use and to have a sufficient number of reliable magnitudes for a statistical discussion, all stars with a measurable photovisual magnitude on a 15-minute plate and lying within a given area (either $6° \times 6°$ or $4° \times 4°$ depending on galactic latitude) surrounding each E region were measured on four photographic and on four photovisual plates. The number of stars included in this programme was 3300, between 200 and 500 per region, compared with the 60 standard stars previously measured. All stars as bright as $10^m{\cdot}2$ photovisual have been observed, and some to $10^m{\cdot}4$.

Included amongst these are 252 stars brighter than magnitude 8·4 in the E regions for which photographic magnitudes have been determined by the Fabry method. These magnitudes which have an internal standard error of $\pm 0^m{\cdot}007$ or less are free from distance error or colour effects varying with magnitude. The parallel programme for photovisual magnitudes to 7·5 is in hand.

The programme for determining the photographic magnitudes of all HR stars brighter than 5·0 and south of declination $+6°$ by the Fabry method is being continued as opportunity offers. These stars are now being connected with the brightest stars in the E regions, so that variation of transparency with azimuth may be checked. This work can be continued on nights when the Moon is too bright for the observation of fainter stars.

During the year photoelectric photometry has been started in an experimental way. A photometer of the Kron type, using a 931-A photomultiplier tube and colour filters, was built and installed on the 7-inch refractor. A considerable amount of work has still to be done before the instrument is ready for a routine programme, but observations already made indicate that it should provide a convenient method of obtaining the colours of the brighter stars and it is hoped to use this instrument to measure the colours of all the stars included in the bright star programme.

From experience at the Cape the photoelectric method does not appear to have advantages over the photographic methods when stars in widely different parts of the sky have to be compared. However, it appears to have advantages for differential work and specially for the observation of the same star in different colours. With visual observations also it is possible to see when atmospheric conditions are vitiating the work. It is thus possible to make satisfactory photoelectric observations even when there are drifting clouds in the sky—i. e. at times when it would be inadvisable to make photographic observations.

Eleven pairs of plates taken by Dr Wesselink with the Rockefeller Telescope at Johannesburg for comparison of certain Kapteyn Areas at $-45°$ with the E regions have been measured at the Cape. These afford a connection between the Leiden and Cape photometric systems.

Routine measurement of the magnitudes of stars in the zones $-52°$ to $-64°$ from plates taken at Pretoria by Dr Redman has been commenced. For the zones $-30°$ to $-40°$ the measurements await the final decision as to the system.

Occultations.—126 observations of 59 phenomena were made with various telescopes at the Observatory. Of these, 97 were disappearances at the dark limb and 23 reappearances at the dark limb. There were 5 disappearances and one reappearance at the bright limb. The principal observers were Mr Davies 49, Dr Stoy 35 and Mr Cousins 23. The data from these observations have been forwarded to the Nautical Almanac Office for discussion, as well as those from 29 occultations observed by Mr S. C. Venter at Pretoria.

Variable Stars.—During 1948 Mr de Kock made 5226 observations of 141 long-period variable stars. Nearly all these observations were made with the 6-inch refractor at the Observatory, the remainder being made with his own 3-inch telescope. The observations have, as usual, been forwarded to Harvard, the headquarters of the American Association of Variable Star Observers.

Mr de Kock also prepared a short note on the irregular variable RR Telescopii, which after having remained fainter than the twelfth magnitude for many years has now brightened to the seventh magnitude.

Comets.—It was reported to the Observatory during the day of Sunday, November 7, that a bright comet had been seen before sunrise that morning. Observations were secured on the mornings of November 8, 9, 10, from which Mr W. P. Hirst computed the first orbit. It continued to be a very bright object in the morning sky till near the time of full Moon and it remained an easy telescopic object till the end of the year. Long-exposure photographs were taken with the Astrographic telescope to show the structure of the head and tail while the comet was bright, and short-exposure photographs were taken for position. The comet, known as the eclipse comet or 1948 l, was photographed on 21 nights during the period November 8 to December 30. Ninety-four exposures have been measured, from which the position has been deduced for the 21 nights of observation. The comet is being observed in January 1949.

Soon afterwards another fairly bright comet, 1948 m, was discovered by Bester at Bloemfontein. From observations made of this comet on four nights, November 26–30, the first orbit was computed by Mr Hirst. This comet remained for some time in a far south declination.

Publication of Observations.—No volume of observations has been issued from the Observatory since 1939. Arrangements have now been made to print Cape Catalogues and Annals by reproduction from typed sheets by photolitho-

graphy. Parts I and II of the Second Cape Catalogue for 1925·0 have been typed and corrected. This volume contains the results of observations made in the years 1925–1932 of 8400 stars south of $-30°$ and of 3367 zodiacal stars. A start has been made in typing the Third Cape Catalogue for 1925·0 and also the details of parallax determinations.

Cambridge Observatories

(*Director, Professor R. O. Redman, F.R.S.*)

Staff.—Dr A. D. Thackeray, Assistant Director of the Solar Physics Observatory, resigned in June to join the staff of the Radcliffe Observatory, Pretoria; and Dr A. Brown, Senior Observer, resigned in August, having been awarded a Commonwealth Fellowship tenable at the Yerkes Observatory. Mr T. Arthur, assistant, retired in March on account of ill health, and Miss J. B. Culpin, secretary, left the staff in July at her own request. The following appointments have been made during the year: Dr E. H. Linfoot, Assistant Director of the Observatory and John Couch Adams Astronomer; Mr M. W. Ovenden, B.Sc., Junior Observer; Mr R. S. Overhill and Mr A. G. Wallman, assistants; Miss R. M. Tuck, secretary. Mr A. B. Partridge, B.A., acted as temporary Observer during the summer. Mr F. Hepburn, B.A., and Dr E. Wolf are working as special assistants under D.S.I.R. grants. Mr E. T. Pierce, B.Sc., Junior Observer, has been on sick leave throughout the whole year. Dr W. H. Steavenson has continued his voluntary work. The following have worked as research students during a part, or the whole of the year: M. K. M. Aly, R. L. Baglow, D. E. Blackwell, I. C. Browne, P. G. F. Caton, P. B. Fellgett, M. G. Fracastoro, G. J. Odgers, G. Righini, J. H. Shaw, L. G. Smith, M. J. Smyth, H. V. Stopes-Roe, P. A. Wayman.

Buildings.—The Huggins, 3-foot reflector, and Northumberland domes have been re-covered in hardboard sheathed in copper. The top shutter of the Newall dome has been replaced. Two small workshops have been established temporarily in the annex of the Northumberland dome. The transit-circle room is being remodelled into a small optical laboratory, the work being about three-quarters complete at the end of 1948. The Huggins darkroom has been divided into two, and one section has been provided with thermostatically controlled electric heating, which helps greatly in the processing of plates during the winter. Temporary accommodation has been provided in Short's aircraft factory, alongside other University departments, for meteorological work.

Instruments.—An unusual amount of overhaul and constructional work has been necessary during the year.

A pulse-counting photometer, with photomultiplier 931-A tube (which can be refrigerated when required) has been made and is now in use on the 15-inch Huggins refractor.

A Schilt-type photometer has been constructed and is now in use for determining stellar magnitudes by photography.

A small grating spectrograph, with $f/1{\cdot}25$ Schmidt camera of $2\frac{1}{2}$ inches focal length, has been made for the 3-foot reflector, and apart from final optical adjustments is ready for use.

A Lyot polarizing filter is in process of construction.

The speed of the microphotometer has been considerably increased by providing it with a 1-valve amplifier and galvanometer in place of the original

Lindemann electrometer. To minimize drift, the valve filament is kept on permanently, the battery "floating" with a trickle charger.

The centre component of the old Sheepshanks 12-inch photovisual triplet, out of use for many years and showing much devitrification, has been repolished by Hargreaves. This lens is being fitted to the Northumberland telescope.

Most of the Observatories' speculum gratings have been aluminized, with measured increase of reflectivity for the mercury green line of between 1·6 and about 5 times. The performance for the mercury green line of the modern Wood grating (ruled in aluminium) has been measured. 93 per cent of the total reflected light falls into one first order, or 69 per cent of the incident light. This grating, with a full $2\frac{1}{2}$-inch aperture, gives approximately the same dispersion as two 60° flint glass prisms. The transmission through the centres of three rather old prisms has been measured for comparison as follows:—

	λ5461	λ4358
2-inch Steinheil	75 per cent	65 per cent
2-inch Brashear, bloomed	84	76
3-inch Cooke	72	55

A newly aluminized plane mirror reflected 85 per cent at λ5461.

The Huggins telescope has been fitted with a Gerrish drive, but the following of the telescope remains poor by modern standards, owing to virtually incurable faults in the sector and bearings.

The 3-foot reflector has been provided with new slow-motion motors and another Newtonian flat.

The transit circle has been presented to the Optical Department of the Imperial College, South Kensington.

Photometry.—Tests of the pulse-counting photometer on actual stars show that with an unselected, but refrigerated, 931-A tube, it should be possible to measur· ɔwn to about 12^m with the 15-inch refractor. Little progress has yet been made with a photometric programme, as most of the time since the first completion of this apparatus has been taken up in accumulating operating experience and in making numerous detailed improvements. On fairly bright objects the instrument can give a mean error of about 0·2 per cent, so that in practice its accuracy will normally be set by the sky.

A comparison of the +15° Selected Areas with the Pole, based on simultaneous photographs in two colours with the Cape photometric cameras, has made satisfactory progress. 40 pairs of plates, each with four three-minute exposures in the order Pole, Area, Area, Pole, have been obtained. The range covered is approximately $7^m{\cdot}5$–$9^m{\cdot}5$ pv. Although the heavy work of measurement has started, and preliminary results for certain areas may be available before the end of 1949, the whole programme is very unlikely to be finished so early.

Photometry of the extra-galactic nebulae with the 3-foot reflector has been continued. Results show that the nuclei of these objects are consistently redder than their outer parts, and, following test measures on star images, this seems unlikely to be due to systematic errors of measurement.

The photometric orbit of RS Sgtr has been computed from observations made at the Radcliffe Observatory, Pretoria.

Incompleted work has included the measurement of eclipsing-variable light curves in widely separated colours, and the development of a new type of photometer, primarily for use with lead sulphide or lead telluride cells.

Stellar Spectroscopy.—Work on the peculiar irregular variable ρ Cass has been published. The reduction and analysis of line intensities in 78 stars of types G5 to K5 have been completed and are ready for publication. The results suggest that there are not more than small variations from star to star of abundance of the elements whose lines have been measured (*Na*, *Mg*, *H*).

Spectra of the individual components of a number of double stars have been photographed with the Newall refractor, with the aim of examining them for variations in chemical abundance. A few attempts, so far unsuccessful, have been made to detect stellar magnetic fields with the same instrument, using a quarter-wave plate and a double-image prism.

Solar Work.—The spectrohelioscope has been used on 101 days for the routine observation of chromospheric flares. Details of 47 of these have been communicated to Meudon and the Cavendish Laboratory. Measurement of the width of $H\alpha$ in all suitable flares is now included in this programme.

The rotational velocity of the Sun has been measured in the light of the chromospheric D3 line of helium, on spectrograms taken some years ago with the McClean solar equipment, and the results are now being prepared for publication.

Attempts are being made by another method to repeat observations equivalent to those of Brück and Rutllant, of displaced Fraunhofer lines after a flare, or before or during a magnetic storm.

Spectroheliograms in $H\alpha$ have been received from Kodaikanal for dates down to 1948 September 30, war-time arrears having now been overtaken.

Optics.—Investigations have been made into the theory of the zonal Foucault test and into the optics of aspherical systems, including both normal and field-flattened Schmidt cameras. Practical optical work has been held up pending completion of the alterations to the transit-circle room.

Physics of the Earth's Atmosphere.—The infra-red solar spectrum has been studied from 3μ to 5μ, with a lithium fluoride prism. Comparisons with laboratory spectra from an absorption tube have led to the conclusive identification of nitrous oxide in the Earth's atmosphere and to a rough estimate of the amount present. The results agree with Adel's earlier work in the United States, although the absorption bands studied are not the same, those observed by Adel being blotted out at any English low-level station by other atmospheric absorption.

Atmospheric Electricity.—A series of observations was made during the summer on the wave-forms of atmospherics from distant lightning discharges, with the collaboration of the Meteorological Office Direction-Finding Organization, which located the individual flashes. New equipment is being constructed to take fuller advantage of this collaboration.

University Observatory, Glasgow

(*Director, Professor W. M. Smart*)

The analysis of the proper motions of the stars of the General Catalogue according to regions and spectral types is proceeding; Dr T. R. Tannahill is mainly responsible at present for this part of the work.

Mr P. A. Sweet's theoretical researches have been concerned with (i) the spontaneous production of large magnetic fields in moving ionized gases, and (ii) the origin of sunspots and the general solar magnetic field.

The Director has been occupied with various problems in celestial mechanics and navigation.

The Observatory has been open on Thursday evenings during the winter terms for the benefit of members of the University and others; various organized parties have also visited the Observatory.

Imperial College Observatory, South Kensington, London

(*Director, Assistant-Professor R. W. B. Pearse*)

Laboratory investigation of molecular spectra has been continued. Mr M. W. Feast has published papers on the Schumann-Runge O_2 bands emitted at atmospheric pressure and on the *CN* tail bands. Dr S. P. Sinha has published further results on the ultra-violet bands of Na_2.

The Observatory, as usual, has been used mainly for courses of instruction.

University of London Observatory, Mill Hill, and University College Observatory

(*Director, Mr C. C. L. Gregory, Wilson Observer*)

The Radcliffe Telescope.—This instrument was used on 126 nights, during which observations made before and after midnight were 81 and 60 respectively. The total number of plates was 466, almost all of which were for parallax; comet 1948 g was also photographed. The 18-inch refractor was used on six nights for measurement of double stars.

Other Instruments.—The Wilson 24-inch reflector and 4-prism spectrograph were used on 42 nights, mostly for obtaining spectra of Be stars. The Fry 8-inch Cooke equatorial, used mainly for instruction, was also used by Mr Peter L. Brown on 12 nights for observations of comets. Owing to an increase in the number of students taking practical instruction, an additional transit instrument was purchased from Dr Waterfield. This has been mounted on the west side of the Radcliffe building under a light-weight "slide off" shelter designed and made at the Observatory; the Grubb chronograph has been adapted to make two transit records at the same time on two sheets of paper. Only slow progress has been made with the mirror meridian instrument, on account of delays in obtaining fused silica and an electric furnace for the adhesion of the silica parts.

Staff.—Mr R. W. Pring resigned his post as First Assistant at the end of April and has been appointed to the Colonial Survey in Africa. Dr E. M. Burbidge (formerly Peachey) has been promoted to the post of Assistant Director, and Miss A. C. Robinson has been appointed Assistant Observer.

Visitors.—The number of visitors was 295.

University Observatory, Oxford

(*Director, Professor H. H. Plaskett, F.R.S.*)

Solar Work.—The solar telescope and spectroscope were in continuous use, apart from a short break caused by the meeting of the I.A.U., from the beginning of March until early November. During the first part of this period adjustments to both instruments resulted in a marked decrease of scattered light and to a slight improvement in the definition and resolving power of the spectroscope.

Early in July P. J. Treanor resumed his experimental work on the application of interferometric methods to absorption-line spectra. By mounting a Fabry-

Perot etalon back of the focal plane of the spectroscope in a beam rendered parallel by an additional collimating lens, he succeeded in getting a new system of heterochromatic fringes in the form of circular channels. Within these channels the solar absorption lines appear as short sections of the normal monochromatic fringe system. This method, briefly described in *Nature*, **162,** 885, 1948, is economical of light, so that highly reflecting coats can be applied to the interferometer plates and a resolving power of the order of 400,000 attained. A full account of the theory and applications of the method will shortly be communicated to the Society.

After some preliminary experiments at the beginning of the observing season, Dr M. G. Adam used the new guiding device to obtain spectra of the extreme solar limb during the period of good seeing in late September and October. These observations will be used in the second part of her study of the Einstein red-shift of solar lines. The first part, based on interferometric measures of solar lines from her observations made in 1946, shows that when the solar wave-lengths are corrected for Lindholm pressure-shift they have a red-shift of only 0·002 A. for the central 75 per cent of the solar disk, and only near the solar limb do they show the predicted Einstein displacement of 0·013 A. (*M.N.*, **108,** 446, 1948). This phenomenon, though not in so clearly marked a form, was first found by St. John in 1928, and was interpreted by him as the result of radial solar currents partially masking the predicted Einstein displacement. From her measures Dr Adam has been able to show that the velocities in these hypothetical radial currents must be so large as to render the hypothesis untenable. There thus appears to be no adequate interpretation of the observed displacements of solar lines, and the only clue seems to lie in the behaviour of these displacements near the limb. It is hoped that the new observations may help to clear up these difficulties.

Other Work.—Dr G. Merton has continued his photographic observations of comets. He has also made substantial progress with his new method of computing the perturbations of periodic comets. *Circulars* 292 to 306 of the British Astronomical Association have been issued under his editorship.

From a discussion of the accidental and systematic errors in the determination of radial velocities from slitless spectra (*M.N.*, **108,** 189, 1948), P. J. Treanor has been led to make several proposals for the modification of existing methods of observation. In particular he suggests a promising variation of Pickering's stellar image method.

University Observatory, St. Andrews

(*Director, Dr E. Finlay-Freundlich*)

Staff.—Mr I. J. Campbell accepted a post with the Admiralty and left the Observatory. In his place Mr T. Ślebarski was appointed Assistant.

Workshop.—The grinding and polishing of the 19-inch principal mirror, the 9-inch secondary mirror and the 20-inch aspheric Schmidt plate for the Schmidt-Cassegrain pilot telescope was completed. The various optical parts are in process of being adapted to the mounting of the 19-inch Grubb-Parsons telescope at the Mills Observatory, Dundee.

Scientific Work.—I. Campbell continued with his theoretical work on the structure of globular clusters and intends to bring his work to a conclusion. T. Ślebarski is occupied with his Ph.D. Thesis. E. Finlay-Freundlich completed and published a paper on the theory of globular clusters.

Experiments were made to use a motor synchronized by a tuned circuit according to a system developed by the Western Electric Company for driving the pilot telescope, and they kindly lent us such a set. It was geared to a contact drum revolving with a period of nearly exactly one second and the speed of the contact drum was recorded on a time recorder, together with the seconds of a sidereal time clock. The experiments were very satisfactory and the method will be put to the test with the pilot model. The plans for the 38-inch Schmidt-Cassegrain telescope are in preparation. The workshop was enlarged by a spacious assembly shop.

Norman Lockyer Observatory of the University College of the South West

(*Director, Mr D. L. Edwards*)

In accordance with the arrangements mentioned last year, the control and management of the Observatory were transferred to University College of the South West (Exeter) on 1948 May 1, at a joint meeting of the two institutions held in the Observatory buildings, Sidmouth. This was an important stage in the history of the Observatory which, it is hoped, will benefit both bodies. Details connected with the new administration, especially methods of developing the Observatory in the future, are under consideration.

Research work has continued as usual, so far as the continued shortage of staff will allow, the main investigation being concerned with relative gradients and colour temperatures of B and A type stars. The technique has been extended, so that both telescopes are now employed mainly for this work, and measures are being made over a wide range of wave-lengths from the near infra-red downwards. Experiments are also being carried out with the object of obtaining absolute gradients through comparison with a standardized laboratory light source.

Observing weather of the quality desirable for the above programme has not been very frequent; but progress has been made, and poorer nights which were unsuited to such photometric work have been used on Be type stars and other minor programmes.

Dunsink Observatory

(*Director, Professor H. A. Brück*)

Considerable progress has been made during the year in the work of reconstructing the buildings and instruments of the Observatory. The basement of the main building has been converted into a workshop and laboratories for optical and other work. The dome containing the 15-inch Roberts Reflector has been re-covered and the telescope itself has been entirely overhauled.

A photoelectric photometer with a photomultiplier tube has been constructed to be attached to the 12-inch South Refractor, but has not been put into use yet, failing the arrival of a suitable galvanometer. The same telescope has been used meanwhile, apart from public demonstrations, for observations of lunar occultations and other phenomena.

Work has started on the erection over the Meridian Room of a steel tower which is to carry the 16-inch coelostat for the projected solar installation. The old 8-foot Ramsden circle in the Meridian Room has been dismantled so as to make

room for a Cassegrainian off-axis solar telescope which is to have an effective focal length of 87 feet. The optical parts for this telescope are being made by Mr Hargreaves, with the exception of a 15-inch concave mirror which, like the coelostat, has been kindly lent to the Observatory by the Joint Permanent Eclipse Committee.

Some plans have been made in conjunction with Dr T. E. Nevin of University College, Dublin, for the erection of a suitable solar concave grating spectrograph which, in an Eagle mounting, is to be set up in the Meridian Room. Arrangements have been made to obtain a 6-inch 7-metre grating with 30,000 lines to the inch from Johns Hopkins University.

Work in America on the "Armagh-Dunsink-Harvard-Telescope" has been progressing satisfactorily, and it is anticipated that this new Schmidt-Baker Telescope will be mounted in South Africa during 1949.

An investigation of intensities of lines in the infra-red region of stellar spectra and their variation with luminosity and spectral type has been completed. This work has been based on spectrograms obtained at the Cambridge Observatory.

Grateful acknowledgment is made here of the most generous response which a special appeal for publications has received from numerous observatories. Altogether several thousand publications have been sent to the Observatory, whose library is now once again largely complete.

Dominion Observatory, Ottawa

(*Director, Dr C. S. Beals*)

Positional Astronomy.—The work of the Meridian Circle and Time Service was carried on as usual. A catalogue of the positions of 2436 stars observed during the years 1911–23 has been published and will shortly be ready for distribution. Observations for the current programme of Backlund-Hough stars is nearly completed and a new observing programme is being drawn up, consisting of Zenith Tube stars and distant stars in the galaxy and in high galactic latitudes.

Plans are being prepared for a new photographic Zenith Tube, and the Meridian Circle is being altered to permit photographic registration of declinations.

Stellar Physics.—While some colour-temperature work and solar observations have continued, the main observational programme of this Division has been in the field of meteor astronomy. In cooperation with the National Research Council the programme of combined radar, photographic and visual observations of meteors, commenced in 1947, was continued. Observations were made on the Lyrids, Eta Aquarids, Delta Aquarids, Perseids, Orionids, Geminids and the summer daylight showers. On this programme a total of over 20 meteor photographs, 3500 visual meteor plots and 1,500,000 radar meteor records were secured in 1948. Three-station radar triangulation of meteor echoes was successfully carried out and the radar echo was shown to agree in position with the visual meteor. A tentative classification of meteor radar echoes appearing in the 30-megacycle (10-metre wave-length) band was proposed and a phenomenological theory to account for their forms was advanced. In connection with this programme the National Research Council used an improved method of determining meteor velocities through the automatic recording of the Doppler meteor whistles.

The construction of two meteor observatories at Meanook and Newbrook, Alberta, was commenced. These observatories will be equipped with the new

Baker-Perkin-Elmer Super-Schmidt Meteor Cameras and will be used for a systematic programme of meteor photography from two stations, in cooperation with the Harvard Observatory, who will be operating a similar pair of stations in the United States.

A number of papers have been published on the subject of meteor observations and one on the temperatures of the P Cygni stars.

Terrestrial Magnetism.—The main feature of the work of this Division has been the continuing effort to secure an adequate network of magnetic stations in the Canadian Arctic. In the summer of 1948 three parties proceeded to the Arctic, two of which made use of icebreaker transportation and the third was transported by an R.C.A.F. Canso aircraft. Twenty-three stations were occupied and the position of the North Magnetic Pole in Northwest Prince of Wales Island was confirmed.

Two new magnetic observatories were established at Resolute Bay, Cornwallis Island and Baker Lake, Northwest Territories. These observatories are making use of recording induction magnetometers designed and constructed at this Observatory.

A publication has been completed, giving 360 values of declination north of 60° latitude collected since 1943.

Seismology.—Operation was continued of the seismograph stations at Ottawa, Halifax, Seven Falls, Shawinigan Falls, Saskatoon and Victoria during 1948. A new short-period Benioff seismograph was installed at Victoria during the year.

In the eastern part of Canada, the study of velocities of seismic waves and the depths of layers in the Canadian Shield by recording rockbursts from mines near Kirkland Lake, has made considerable progress. Stations have been occupied up to a distance of twenty-five miles during the summer. In the winter these stations, with their portable huts and modified Sprengnether seismometers, are moved to points more distant from the source of seismic energy in the direction of Ottawa. Considerable success can be reported from recordings at both summer and winter positions.

The study of local earthquake activity in the east is being continued. A final report on the location of the Cornwall-Massena earthquake of 1944 has been published. During 1948 there were several very slight earthquakes along the St. Lawrence valley. A report on the one of January 1, below Quebec City, has been published. Another study of an earthquake near Montreal on May 9 is being made.

A study of conditions in the Arctic is being conducted with a view to establishing a seismograph station in that region in the near future.

Gravity.—Gravimeter observations, using a "North American" instrument, were carried out with the aid of aerial transportation in the Northwest Territories, 200 stations being established in an area of 150,000 square miles from the Saskatchewan and Alberta borders north to Great Slave Lake. Using the same gravity meter three hundred gravity observations were made in the vicinity of Lake Shore Mines and Noranda, underground observations being carried to the 7000-foot level. A further traverse by rail was made between Quebec City and Cochrane, Ontario, 70 stations being occupied.

A second gravimeter of Mott Smith type, mounted in an automobile, was used to occupy 300 stations in the region of the Sudbury Basin, as well as an additional 200 on the highways between Quebec and Saskatchewan. Work is proceeding on the analysis and interpretation of the observations. Two papers have been published and others are in course of preparation.

David Dunlap Observatory, University of Toronto

(*Director, Professor F. S. Hogg*)

Staff.—Professor Ching-Sung-Yu, of Nanking, China, who served as visiting lecturer for the years 1946–1948, has left to join the staff of the High Altitude Observatory at Boulder, Colorado. Mr R. L. Baglow has been appointed as a lecturer.

Radial Velocities.—During 1948 the regular programme of radial velocity observations of the later-type stars, brighter than 9·0 photographic, in the Yale zone 25° to 30° has been continued. In some regions the observational work is substantially completed. Orbits of several spectroscopic binaries have been computed. Professor J. F. Heard has investigated eight β Canis Majoris type stars, and developed statistical criteria as to the justification of so classifying the selected stars. This work is being published in the *Astrophysical Journal*, 1949 March.

Photometry.—In globular clusters, Dr Helen Sawyer Hogg has concentrated particular attention on the longer-period variable stars, and discovered that a number of these belong to the RV Tauri class. She has also completed light curves of cluster-type variables in Messier 9 and 14. A graduate student, Mr W. R. Hossack, has taken many multiple, short-exposure photographs of the fields of white dwarf stars, to search for short-period variations. Mr Baglow has used the photomultiplier photometer in the study of eclipsing binaries. He has replaced the batteries with a controlled power-line source.

Miscellaneous.—Professor R. E. Williamson and a student, Mr G. F. D. Duff, have integrated equilibrium equations in stellar models of the fainter main sequence stars. Some of the results of these computations are appearing in the *Monthly Notices*. Professor Williamson has continued to serve as consultant in the United States Navy and Cornell University microwave astronomy project. With Miss R. J. Northcott he has determined the position of the galactic plane, as indicated by the microwave results of a number of observers. Mr D. K. Norris has been collecting and analysing atmospheric dust, in a search for particles of meteoritic origin.

During the year *D.D.O. Communications*, Nos. 15, 16 and 17, have been published, while several others are in press.

Union Observatory, Johannesburg

(*Union Astronomer, Dr W. H. van den Bos*)

With the 26½-inch refractor 494 micrometer and 12 interferometer measures of double stars were obtained. Finsen has made an interferometer, permanently attached to the micrometer. It is at present mainly used for a systematic survey of stars down to the sixth magnitude and between the equator and 60° south declination.

Plates taken with the Franklin-Adams telescope were:—

Minor planets	295
Comets	134
Variable stars	120
Miscellaneous	37
Total	586

Comet 1948 j was discovered by E. L. Johnson.

With the 9-inch refractor 85 occultations have been observed. Counts of sunspots with the 3-inch refractor were made on 334 days.

During the year 902 visitors were admitted.

A quartz crystal clock installation for the modernization of the time service is on order. One quartz clock unit was constructed in our workshop and is undergoing preliminary tests.

Circulars No. 105 and 106 and the Index to Volume 4 were printed and distributed.

Drs Woolley, Brouwer, Schilt and Oort visited the Observatory. The Union Astronomer attended the I.A.U. meeting at Zürich and visited a number of scientific institutions in England and Holland.

There were no changes of staff.

Radcliffe Observatory, Pretoria

(*Director, Dr H. Knox-Shaw, Radcliffe Observer*)

The event of the year was the arrival in April of the 74-inch mirror, nearly thirteen years after the order was placed for the pyrex glass disk. Considerable modifications in the cell and mirror supports, and in the balancing of the telescope, were necessitated by the mirror being two inches thinner than originally planned. And in consequence it was six weeks later before the first photographic trials could be made. The images were found to be slightly astigmatic, and after a series of tests which involved taking down the cell from the telescope several times and eventually lifting the mirror out of the cell, the cause of the astigmatism was located in the back supports of the mirror and was successfully removed.

As neither the Cassegrain nor the coudé mirrors have been finished, and no spectrographs have yet been received, the telescope can only be used as a Newtonian for direct photography, and with it in that form about 150 plates have been taken of nebulae, globular clusters and interesting stars in the southern hemisphere, including the nebulosity around η Carinae; the variable of very short period, VV Puppis; and three long-period variables in 47 Tucanae. In addition a series of exposures was made of Jupiter, and some 70 plates were obtained to test the adjustment and powers of the telescope. Most of the observational work was done by Dr A. D. Thackeray, who joined the staff as Chief Assistant in July.

Nizamiah Observatory, Hyderabad

(*Director, Dr Akbar Ali*)

Astrographic Equatorial.—For lack of photographic supplies from England, only a few repetition plates were taken with the Astrographic Equatorial. The recently published measures of stars in the Hyderabad Astrographic Catalogues are being compared with the Potsdam measures for deriving the proper motions of stars in zones $+36°$ to $+39°$. Six common regions were compared by the Director during the year. It is proposed to complete this work by comparing the remaining 28 regions. The reductions of the Eros plates are in progress and it is hoped to publish the results after reducing the remaining 44 plates. The survey of the double stars in zone $+37°$ has been taken up and a major portion of this work has been completed. The comet 1948 l was photographed for measure-

ment of its position several times with the Astro Camera attached to the guiding telescope of the Astrographic Equatorial.

Grubb Equatorial.—The total number of occultations observed during the year was 32. They have been reduced and their results are, as usual, being communicated for publication in the *Monthly Notices*. The programme of the measurement of double stars has been continued as before.

Spectrohelioscope.—The routine observations of the Sun with the spectrohelioscope were carried out as usual.

Publications.—The following papers were sent for publication or are ready for press:—

1. "Occultations of stars by the Moon observed at the Nizamiah Observatory during 1947" (sent for publication).
2. "Faint stars with proper motions exceeding 0″·15 per annum in Hyderabad Astrographic Zones, List VI" (sent for publication).
3. "Note on the double star ADS 3946" (ready for press).
4. Vol. VIII, Part II of the series of publications of the Observatory dealing with the comparison of the places of stars in the Washington Catalogue, with the photographic measures on the plates of the Hyderabad Section of the Astrographic Catalogue (ready for press).

Miscellaneous.—The meteorological and seismological work of the department has been continued as usual. The *Seismological Bulletin*, No. 1, of the Nizamiah Observatory for 1942–1944 was distributed to the important seismological stations. Mr M. Nataraja Pillay of the Travancore Observatory underwent practical training at the Observatory for three months. Mr H. S. Ramannah, Senior Observer, retired during the year. Mr M. V. V. Sastry, Senior Observer, took leave, preparatory to retirement.

Solar Physics Observatory, Kodaikanal

(*Director, A. K. Das*)

General.—A noteworthy feature of the year was the visit to this Observatory of Professor S. Chapman, Sedleian Professor of Natural Philosophy at the University of Oxford.

The old Magnetic Observatory which was closed down in 1923 was restarted and systematic observations of the magnetic elements were commenced from 1948 November 1.

Exchange of spectroheliograms with foreign observatories continued as in previous years. 281 K-flocculus plates relating to the period 1947 October to 1948 September were supplied to the Solar Physics Observatory, Cambridge, and seven photoheliograms for specified dates to the Royal Observatory, Greenwich. 141 K-flocculus and 174 $H\alpha$-flocculus photographs relating to the period 1942–48 were received from the Meudon Observatory, France. The Mount Wilson Observatory supplied 91 K-prominence and 78 $H\alpha$-flocculus plates relating to the period 1947 January to 1948 June.

Routine Observations.—Weather conditions were generally less favourable during 1948 than during the previous year. The average definition of the Sun's image before 11 a.m. (I.S.T.) estimated on a scale in which 1 is the worst and 5 the

best was 2·8 compared to 2·7 of the previous year. On 83 days the definition was 2 or less, while on 26 days it was 4 or more. Observations of the sky conditions described in last year's report were continued. Systematic observations of sky and seeing conditions at 21^h, 00^h and 03^h every night were commenced from 1948 October 1. Observations with the photoheliograph, the prominence spectroscope, the spectrohelioscope and the spectroheliographs were carried out as usual. Direct photographs of the Sun, on a scale of 8 inches to the Sun's diameter, were obtained on 305 days as against 304 in 1947. Disk spectroheliograms in the *Hα* and K lines were obtained on 286 and 275 days respectively, and K-prominence plates were secured on 274 days. Quarterly statements of chromospheric eruptions were sent to Dr L. d'Azambuja of the Meudon Observatory and Mr H. W. Newton of the Royal Observatory, Greenwich.

Sunspots.—The number of new sunspot groups observed during the different months of the year, their distribution in the two hemispheres and the mean daily numbers are given in the following table:—

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
No. of new groups	North	16	11	10	16	14	14	13	12	11	16	17	17	167
	South	19	22	14	20	15	13	20	19	16	14	6	17	195
	Total	35	33	24	36	29	27	33	31	27	30	23	34	362
Mean daily No.		7·7	5·6	4·2	9·7	6·9	8·1	7·4	10·0	6·5	6·3	5·6	7·0	7·1

Compared with 1947 the total number of new spot groups shows a decrease of 15·7 per cent; the mean daily number also shows a decrease of 12·3 per cent. There were two days on which the Sun's disk was free from spots. The approximate mean latitude of the sunspot groups for the whole year was 14° as against 17° of the previous year.

Research Work.—Measurements made on a number of spectrograms of the H and K lines obtained under good atmospheric conditions with a 14-foot Littrow prism spectrograph (mean dispersion 0·45 A./mm. in this region) at various points of the solar disk showed that while the widths of H_3, H_2, K_3 and K_2 increase progressively from centre to limb, their ratios $K_3 : K_2$, $H_3 : H_2$, $K_3 : H_3$ and $K_2 : H_2$ remain practically constant all over the disk. The mean values of the width ratios obtained from these measurements are $K_3 : K_2 = H_3 : H_2 = 0{\cdot}68$ and $K_3 : H_3 = K_2 : H_2 = 1{\cdot}1$.

A statistical study of the *Hα* dark markings over a whole solar cycle (1933–1943) showed that the length to height ratio is most frequently 2 : 1. A parallel study of all clearly arch-type prominences photographed in the K line during the period 1908–1940 at Kodaikanal also showed that the ratio base : height was most frequently 2 : 1. From these results it may be inferred that the fundamental shape of quiescent prominences is the semi-circular arch, all other forms being probably variants of the fundamental type. Incidentally, this inference lends support to the theory of formation of prominences proposed by A. K. Das some years ago.

Commonwealth Observatory, Mt. Stromlo

(*Director, Dr R. v. d. R. Woolley, Commonwealth Astronomer*)

Solar Work.—The daily routine of sunspot sketching has been maintained. Registration of 200 Mc./s. solar radiation has been continued and compared when possible with spectrohelioscope and ionospheric observations.

Theoretical investigations and numerical analyses have been made relating to the various regions of the ionosphere.

The variation of the breadths and intensities of 20 Fraunhofer lines across the Sun's disk has been studied from photometry carried out in 1939.

Time Service.—Transit observations for clock error were secured on 153 nights. Rhythmic time signals have been transmitted three times daily from Belconnen Naval Wireless Station, and correction sheets issued.

The quartz clock installation comprising three crystal oscillators and associated equipment has been received and put into operation. An electronic counter chronograph has also been received and is in regular use. A considerable amount of auxiliary electronic equipment is being constructed in the Observatory.

Astronomical Observations.—The comparison between the magnitude of the Sun and Sirius has been completed, and the results communicated to the Society for publication. The value found for the Sun's absolute photovisual magnitude was $+4{\cdot}52$. This was based on a photovisual magnitude for Sirius of $-1{\cdot}52$, but more recent photoelectric work on Mount Stromlo indicates that the magnitude of Sirius should be revised to about $-1{\cdot}3$, which would make the Sun's photovisual magnitude about $-4{\cdot}7$, in good agreement with the present accepted value. Photographic observations of stars reported as spectrum variables, but not light variables, were continued with the electron multiplier photometer on the Farnham refractor. A total of 4675 observations were made on 126 nights, the stars mainly observed being ξ Phoe, μ Cent, α Cari and θ^2 Cruc. The first has been found to be an eclipsing binary, the remainder show small variations of light.

A multiplier photometer with arrangements for refrigeration has been fitted to the Oddie refractor. A programme of monochromatic photometry of brighter southern stars has been commenced with the Reynolds 30-inch reflector. Measurements are being made in the band 4500–4600 A., the dispersion being obtained with a slitless spectrograph and the light intensities measured with an electron multiplier.

Good progress has been made with the colour gradient programme. Eighty-two plates comprising about 1800 spectra have been obtained during the year. Eight plates have been reduced so far. It is already clear that at least a dozen of the Mount Stromlo stars will be bluer than any on the Greenwich gradient programme. Some of these (notably α and β Cruc, β Cent and α Virg), may well be the bluest stars yet measured. In the course of the programme λ Pavo was found to have developed strong emission lines, and a note to this effect sent to *The Observatory*.

Reclassification of the objective prism spectra taken by Mr Rimmer on the Oddie refractor has proceeded steadily throughout the year. A nebular spectrograph similar to that installed at the McDonald Observatory has been constructed and put into operation. Twenty-nine spectrograms have been obtained of the night sky, nebulae and of other objects.

48-inch Reflector.—The design of this instrument is now well advanced, and work has been commenced on the piers. The existing speculum mirror is to be replaced by a glass mirror, a contract for which has been let to Messrs Cox, Hargreaves and Thomson Ltd. Delivery is expected early in 1950. It is hoped to make rapid progress with this telescope and to have it in commission by the end of 1950.

74-inch Reflector.—The contract has been placed with Sir Howard Grubb, Parsons and Co. for the construction and delivery of this instrument.

Miscellaneous.—Work has been continued on the preparation of the Melbourne Catalogue ME 4 for publication.

The 3-prism slit spectrograph to be used initially on the Reynolds 30-inch and later on the 48-inch reflector is now under construction in the workshop, and should be ready for testing by the middle of 1949.

Riverview College Observatory, Riverview, N.S.W.

(*Director, Rev. D. O'Connell, S.J.*)

The Director was absent for the greater part of the year. He attended the I.A.U. and I.U.G.G. meetings, worked for some time at the Leiden, Vatican and Harvard Observatories and visited other observatories in Europe and America.

Photographic work on variable stars and observations of occultations were continued during the year. The number of clear nights was above the average.

Publications.—*Publication* No. 8 (Vol. 2, No. 4) was distributed during the year.

Sydney Observatory

(*Government Astronomer, Mr H. W. Wood*)

The programme of work on the astrographic catalogue has been continued and volumes 25 and 27 were issued and volume 28 is now in the hands of the printer.

The occultations predicted in the *Nautical Almanac* have been observed when possible. The results for 1947 have been published and those for 1948 prepared for publication. A series of visual observations of double stars has been published and measurements have been continued of double stars appearing on plates taken for the astrographic catalogue.

Resources have been made available for new equipment for the Observatory, including a new dome to house the astrographic telescope, a modern photographic lens for positional work, and a coordinate measuring micrometer. The lens is to be of 9 inches aperture and 70 inches focal length and the micrometer to measure square plates of side 7 inches.

The civil work, consisting of the supply of astronomical information for legal purposes and time service and answering general enquiries, has been carried on.

The educational work of the Observatory was continued and lectures and demonstrations were delivered regularly.

Perth Observatory

(*Government Astronomer, Mr H. S. Spigl*)

Efforts to increase the staff have not yet been successful, the staff consisting of a general assistant, Mr D. B. Lambert.

The West Australian Standard time service has been maintained and distributed by Onogo, hourly, and other time signals.

The seismograph record was complete, with the exception of a few weeks due to power failures, and records were distributed in quarterly bulletins to 40 cooperating stations.

Generally five nights per month are devoted to visitors, approximately 1000 being present at evening demonstrations throughout the year, and a lesser number at day visits. Lectures have also been delivered at various gatherings, and the Government Astronomer also undertakes certain University lecturing.

During the year observations of sunspots by projection have been made, and various astronomical phenomena observed.

Astronomical tables of various phenomena are distributed for a number of places throughout the State. Astronomical information for legal purposes and general enquiries was furnished when required. The tide tables for Port Hedland and the North West Coast, incorporating astronomical data, were duly completed and distributed.

Carter Observatory, Wellington, N.Z.

(*Director, Mr I. L. Thomsen*)

From February to December the Observatory was open regularly to the public on Friday evenings, when lectures and telescope demonstrations were given. Attendances totalled 1421 in spite of unfavourable weather.

Observations of sunspots by projection have been made continuously and counts reported to Zürich Observatory. Forecasts of radio disturbances based on solar data have been made to the Post and Telegraph Department and the New Zealand Broadcasting Service as formerly, with satisfactory results. Observations with the spectrohelioscope have been made whenever possible and special attention given to the work in 1948 July, at the request of Greenwich Observatory.

Auroral observations have been collected from all sources as in previous years. Past observations commencing from 1931 to date have been rearranged preparatory to a complete discussion of the work which it is hoped will commence in 1949. Discussions with Government authorities have given hope of establishing a photographic base line in the South Island for parallax work next year.

Occultation observations made at Wellington, New Plymouth and Dunedin have been collected preparatory to sending to H.M. Nautical Almanac Office.

Mr K. D. Adams has been developing photometric apparatus, using a photomultiplier tube, for use with the 5-inch telescope. The supply is from 230-volt, 50-cycle mains, which is stabilized satisfactorily by a design of his own. It is hoped to commence work in 1949. Apparatus is also being collected for similar work with the 9-inch telescope, to be used by an honours student.

A large number of observations of Comet 1948l were collected, and await reduction, but no observations were made at the Observatory owing to the distance of the Director's residence. An ephemeris was computed for this comet, and general comet information distributed to all active amateurs in the Dominion throughout the year.

The Radio Research Section of the Dominion Physical Laboratory were given quarters in the Observatory from May onwards.

The Observatory received as a gift from Mrs A. C. Gifford the complete astronomical library of her late husband, as well as the original manuscripts,

papers, etc. of the late Professor A. W. Bickerton. Many valuable gifts have also been received from Dr L. J. Comrie.

In the early part of the year visits were received from Dr L. J. Comrie, Scientific Computing Service Ltd., London, and Dr C. W. Allen, Commonwealth Observatory, Mt. Stromlo. These provided valuable opportunities for discussion.

Dominion Observatory, Wellington, N.Z.

(*Director, Mr R. C. Hayes*)

The only work of an astronomical nature carried out during the year was the maintenance of the National Time Service. In this connection, a new method for the automatic recording of overseas radio time signals, developed during the year 1948, has resulted in the maintenance of more accurate time than previously.

The Observatory of the Hampstead Scientific Society

(*Astronomical Secretary, H. Wildey*)

Longitude	$0^h\ 10^m\ 42^s$ W.
Latitude	51° 33′ 36″
Altitude	450 ft.

The 6-inch Cooke refractor was visited by 400 visitors, who were shown the celestial sights, when weather permitted, on Monday, Thursday and Saturday evenings. In addition to this, 230 observations of variable stars and novae were made, several comets were followed, Mars, Saturn and Jupiter were sketched and central transits and colour estimates recorded. The Sun was observed on 30 days and sketches made of spots and prominences. All observations were sent to the British Astronomical Association Section directors.

Mr F. Addey's Observatory

Buckhorn Weston, Dorset

Sunspot observations at Buckhorn Weston were commenced on 1948 May 17 and continued till 1948 October 27, when they were suspended owing to a move to Long Sutton, Somerset. Observations at the new address have not yet been commenced.

During the period mentioned 149 whole disk Sun drawings were made and six naked-eye spots were observed. All drawings and reports were forwarded to the British Astronomical Association.

Mr R. Barker's Observatory, Cheshunt, Hertfordshire

Mars' opposition, though difficult of observation owing to the smallness of the disk presented, was of great interest and afforded much general detail. Only 16 good seeings were obtained during February and March. The Phison was seen doubled on March 10, and Trivium Charontis appeared on February 9 as a triangular junction for many radiating canali.

Frequent observations of the lunar walled plain Aristarchus have confirmed the dusky markings on the eastern inner wall. These markings have now developed from simple radial bands into a complex chequerwork, and this

evolution is still proceeding, thus marking what is believed to be the first really definite physical change ever recorded on the Moon.

Mr J. Evershed's Observatory, Ewhurst, Surrey

A number of high dispersion spectra of the centre of the Sun's disk in a limited region between λ6280 and 6300 were photographed and measured during the year. The results from all measures of this region made in recent years, including a large number of limb spectra, have been published in *M.N.*, **108**, 347.

It is shown that appreciable changes of wave-length in the stronger iron lines have occurred when comparisons are made with spectra obtained at Kodaikanal in 1914–15 and with the standard solar wave-lengths of the I.A.U. published in 1928.

A new dispersing liquid has been used with success in the prisms. At the suggestion of Sir Robert Robinson, experiments were made with α-chloronaphthalene, and this liquid was found to be equal in dispersion to the bromine or the methyl derivatives of naphthalene. It has the advantage of being perfectly colourless when freshly distilled.

Mr M. B. B. Heath's Observatory, Kingsteignton, Devon

Daylight observations of Mercury were made on 29 days and of Venus on 79 days; four drawings were made of Mercury and 13 of Venus; Mars was observed on 31 nights and 14 drawings made. Saturn was observed on 38 nights, Saturnicentric latitudes of edges of belts being made on 30 nights and comparisons of satellite magnitudes on 34 nights. All results were sent to the British Astronomical Association. Among occasional phenomena the occultation of Mars on January 28 and the penumbral eclipse of the Moon on October 18 were well observed.

Mr F. M. Holborn's Observatory, Streatham, London

During the year 2013 observations were made of 65 variable stars and five novae on 175 nights. The Sun was observed on 203 days for spot counts and naked-eye spots. All records were sent to the British Astronomical Association.

Mr F. J. Sellers' Observatory, Muswell Hill, London

Serious work has been confined to solar observation with the 5-inch equatorial, spectroscope and spectrohelioscope. Summaries of general solar activity are submitted periodically for publication in the Journal of the B.A.A.

Particulars of 45 chromospheric flares, which have been observed and recorded since 1948 January 1, together with the total times of observation, have been communicated to Dr d'Azambuja at Meudon for inclusion in the *I.A.U. Bulletin*, to the Cavendish Laboratory, Cambridge, and to Mr J. S. Hey at Byfleet, Surrey. Well observed major outbursts have also been reported to Greenwich Observatory.

Observing conditions during the year have been generally very poor owing to cloud haze and fog, especially since June. Considerable observation in D_3 and $H\beta$ has been greatly facilitated by the achromatic objective recently installed.

Dr W. H. Steavenson's Observatory, Cambridge

The 30-inch reflector has been used chiefly for photometric observations of old novae, and the results for 1947 have been communicated to the Society.

Observations of the position-angles and magnitudes of the satellites of Uranus have been continued and the preliminary results of this work have been communicated to the Society.

Photometric comparisons of Pluto with neighbouring stars were made on a number of nights. Physical observations of four comets were made and have been communicated to the Comet Section of the British Astronomical Association.

Dr R. L. Waterfield's Observatory, Silwood Park, Sunningdale

The Player equatorial (6-inch refractor and 6-inch photographic triplet by Cooke), which was previously installed at the observatory of the late T. E. R. Phillips, has been unused since the outbreak of the war and in 1944 its building was seriously damaged by a flying bomb. Last year the Governing Body of the Imperial College of Science kindly offered a site for its re-erection in the grounds of their Field Station at Silwood Park, Sunningdale; by the end of the year the instrument was erected and ready for use. Thanks are due to the Imperial College for their kindness in providing not only the site but also the use of a concrete hut, which has been adapted as a darkroom and workroom, and especially to Professor J. W. Munro, Director of the Field Station, for many kindnesses and for his personal help in the repair of the equipment. The photography of comets has been begun; the programme in view is the measurement of cometary positions and the study of their light variations. The B.A.A. Council has kindly lent the Will Hay Blink Comparator and the construction of a measuring microscope has just been completed.

Mr H. Wildey's Observatory, Hampstead, London

The 12½-inch reflector was used to make 450 variable star and novae observations, and Mars was sketched when possible. Saturn was also followed, but Jupiter was unobservable. The physical appearance of comets was noted and all work sent in to the Sections of the British Astronomical Association.

Work is going on well with the spectrohelioscope and it is hoped that this instrument will be completed and in use during the coming year.

Mr H. P. Wilkins' Observatory, Barnehurst, Kent

Observations of the Moon and planets have been conducted with the 12-inch and 6-inch reflectors, and micrometrical measures of the positions and diameters of 200 lunar formations, situated near the limb, have been secured with the 12-inch.

Mr Wilkins in his capacity as Director of the Lunar Section of the British Astronomical Association has dealt with an extensive correspondence and has received a large number of drawings, the classification of which has somewhat curtailed observation. Many previously unrecorded details depicted on these drawings have been confirmed and incorporated on the 300-inch lunar map.

REPORTS ON THE PROGRESS OF ASTRONOMY

RADIO ASTRONOMY

J. S. Hey

1. *Introduction.*—The investigation of astronomical phenomena by their radio emissions or by radio reflections from them has provided some striking discoveries during the last few years. This advance has been due in no small measure to the improvements in sensitivity and directivity of the radio receivers and transmitters used for radar during the war. These operated on wave-lengths, ranging from several metres down to several centimetres *, which were sufficiently short to penetrate the ionosphere. Certain radio-astronomical phenomena became apparent because they interfered with normal radar operation, and these observations provided starting-points for fundamental research when the war ended. The beginnings of radio astronomy came some years before the war and the historical development is outlined in later sections of this report; but only in recent years have techniques advanced and knowledge increased sufficiently for the potentialities of this new science to be adequately appreciated.

Radio methods have been applied to three branches of astronomy. The first is the observation of radio reflections from celestial objects or the ionization effects they produce. For this, radar equipments enable the directions and range of the echoing source to be measured. An extensive study of meteors by means of reflections from ionization trails has already been achieved. Reflections have also been obtained from the Moon; and with future developments in high-powered transmitters and more sensitive receivers we may expect that other planetary bodies will be detected by radar.

The other two branches of radio astronomy, the reception of radio emissions from the Sun and the Galaxy, have some features in common. For these, a radio receiver only is required, and it so happens that the type of receiver used for radar has particularly suitable characteristics, for example in wave-length, directivity and high sensitivity, so that such receivers have often been adapted for this purpose. The received emissions show random fluctuations of amplitude and produce a hissing noise in headphones connected to the receiver output. Hence the emissions are known as radio noise. This noise of extra-terrestrial origin has amplitude characteristics which appear indistinguishable in form from the noise generated in the receiver due to the random agitation of electrons in resistors and valves. The receiver noise is the important factor limiting receiver sensitivity.

Extra-terrestrial radio noise other than that from the Sun has sometimes been termed cosmic radio noise or cosmic static. There are, however, two main sources of extra-terrestrial radio noise, the Sun and the Galaxy, and it is therefore now becoming more usual to describe the noise by the adjectives "solar" and "galactic" respectively, and to avoid the term "cosmic" which is apt to lead to confusion with cosmic rays.

* Frequency in megacycles per sec. (Mc./s.) is given by $300/\lambda$, where λ is the wave-length in metres.

Radio astronomy has developed rapidly, and the number of published papers is already large. It will not be possible to discuss all of them without overburdening the report. Consequently, not all the publications in the list of references are mentioned in the text, which attempts to outline the main trends of progress.

2. *Some Fundamentals of Radio Transmission and Reception.*—Before attempting to review the progress in these three branches of radio astronomy, some principles of radio will be outlined in order to make the account self-contained and to assist those unfamiliar with the subject. The general remarks below aim at showing how the physical principles of wave optics and thermal radiation apply at radio wave-lengths.

We will first consider the aerial systems used for transmission; the same results apply to reception in consequence of the Reciprocity Theorem. For wave-lengths greater than a few centimetres, the transmitted power is fed directly into one or more resonant dipole radiators of length about $\frac{1}{2}\lambda$ or λ, where λ is the wave-length. A single dipole in free space would give a very wide beam of transmitted power with maximum intensity perpendicular to its length and zero in the end-on direction. A dipole in free space is an ideal consideration, and in practice the pattern of radiation intensity would be modified by interference effects with ground-reflected waves.

It is fairly simple to take into account reflection from flat ground for horizontally polarized waves (the polarization denoted here by the direction of the electric field vector) which would be radiated by a horizontal dipole. In this case the reflection coefficient is nearly -1 for most types of ground, for wave-lengths of the order of a metre. Then the radiated field is the interference pattern obtained by combining the wave from the dipole with that from its mirror image, with 180° change of phase in the ground. With vertical polarization the effect is more complex, for as in light the Brewster phenomenon occurs; when the angle of incidence equals the Brewster angle the reflection coefficient reaches a minimum and changes sign.

In certain applications deliberate use has been made of ground reflection to obtain particular structures in the radiation pattern in a vertical plane. This necessitates special siting of the equipment on flat ground, or alternatively the use of extensive wire-netting mats to provide a more uniform and perfect reflecting surface.

The more common requirement, however, is for a narrow beam in order to obtain high angular resolution and to avoid ground reflection. At wave-lengths less than a metre, parabolic reflectors are practicable. As in optical instruments the aperture measured in wave-lengths determines the angular resolution, and the angle θ from maximum to first minimum in the diffraction pattern is given by $\sin\theta = 1{\cdot}22\lambda/d$, where d is the diameter of the aperture. For radio wave-lengths the aperture is only several wave-lengths in diameter and consequently the angular resolution is low. With paraboloid apertures of these dimensions and with a dipole aerial at the focus the radiation pattern is slightly different from the ideal case of a uniformly illuminated aperture, but to a first approximation the beam dimensions are given by simple optical wave theory. It is usual in radio to define the beam-width in any plane as the angle between the directions at which the transmitted power has half the maximum value. This defines the most important part of the beam and is preferable to any definition involving the minimum, since this is less accurately measured (and departures from simple wave theory considerations tend to be more apparent also).

At very short wave-lengths—of the order of 1 cm.—the transmitted power may be fed to the parabolic reflector from a rectangular hollow tube known as a waveguide. It also becomes possible to use, instead of paraboloids, waveguide or other structures which simulate the action of a lens.

At wave-lengths greater than a metre, parabolic reflectors are generally impracticable because of the large size needed to give a narrow beam, particularly if it is desired to make the paraboloid adjustable in direction. The difficulty cannot altogether be avoided, but it is easier to construct various types of arrays. For example, the power may be divided among a flat array of dipoles in the same phase and with a flat wire-netting reflector behind them. The radiation pattern is the wave summation of the radiation from all the dipoles. Another type of array is the Yagi-array in which a dipole has a parallel reflector behind it and a number of parallel "directors" in front. The reflector and director dimensions and spacings are chosen empirically. For adjustable aerial systems the beamwidths commonly used vary between about 40° and 50° for wave-lengths ranging from several millimetres to several centimetres respectively. Narrower beams are practicable for aerials which are fixed or with a limited movement.

For a receiver aerial the same factors discussed above determine the beamwidth sensitivity to power flux received from different directions. As mentioned previously, this follows from the Reciprocity Theorem. Beam patterns of transmitters may be measured with the aid of balloons carrying field-strength measuring apparatus, and of receivers by observing the received power from an oscillator suspended from a balloon. Instead of balloons, aircraft may be used with advantage in some circumstances. For radar, beam patterns may also be determined by echoes observed from spherical reflectors supported by balloons.

The radiation pattern is often described in terms of the power gain relative to either an idealized isotropic aerial or a half-wave dipole in free space. Suppose that in the direction of maximum radiation the emitted power is G times that of an isotropic radiator, and let $F(\theta, \phi)$ be the factor representing the variations of power with respect to the coordinates (θ, ϕ) of angular direction. Since the total power is the same for the given aerial as for the isotropic radiator, we have

$$G\int_{4\pi} F(\theta,\phi)\,dw = 4\pi, \qquad (1)$$

where dw is an element of solid angle in direction θ, ϕ. By the Reciprocity Theorem the same relationship applies to the power sensitivity of a receiving aerial. It is thus not possible by any aerial structure, however large, to have in a receiver both high aerial sensitivity and a broad beam.

The gain of an aerial is sometimes described in terms of an effective area A of imaginary aperture. The relationship between G and A can be derived by reference to wave optics. From diffraction theory of a uniformly illuminated aperture we know that if E is the wave amplitude, then the maximum amplitude at distance r is $EA/\lambda r$. The corresponding power as compared with that of an isotropic radiator gives the power gain. Since power is proportional to the square of the field amplitude, we have

$$\frac{GAE^2}{4\pi r^2} = \frac{E^2A^2}{\lambda^2 r^2},$$

or

$$G = \frac{4\pi A}{\lambda^2}. \qquad (2)$$

Since an aerial dissipates power by radiation it is equivalent to an impedance of which the resistive component is called the radiation resistance. Thus, if P is the radiated power and I the current at the aerial terminals, the radiation resistance R is given by

$$P = I^2R. \tag{3}$$

It is important at all stages in transmitters and receivers to see that the conditions for maximum power transference are fulfilled. This involves a well-known principle applying to any generator, namely that there is maximum power transference to the "load" when the load impedance equals the internal impedance of the generator. This is known as "matching" and the power transferred when impedances are matched is termed available power. Thus the aerial impedance should equal that presented by the transmitter or the receiver. In the latter case the incident field generates the power in the aerial and (assuming negligible ohmic resistance) the power re-radiated corresponds to the power dissipated in the generator.

For radar transmitters, pulses of the order of a microsecond in duration are transmitted at intervals of $\frac{1}{100}$ to $\frac{1}{1000}$ second. The peak powers are usually of the order of 100 kilowatts, but the mean power is comparatively small because ratio of interval to pulse duration is large. When a pulse is transmitted, a cathode ray beam at the receiver is deflected at a regular speed. This produces the "time-base" or "range trace" because the received echo is displayed on the cathode ray trace, either as a deflection perpendicular to the trace or as a modulation of the intensity, and the position at which the echo appears on this trace indicates its range. Range accuracies of about 15 m. $\pm$ 0·5 m. per km. may be achieved.

The radio-frequency part of the receiver consists of a sensitive amplifier, usually incorporating a frequency changer (and it is then known as a superheterodyne receiver), since many stages of amplification at a single very high frequency present considerable practical difficulties. It is therefore easier to mix the received signal with a small oscillator in the receiver so as to produce a beat of lower frequency. The amplifier is followed by a detector to provide a rectified D.C. output corresponding to the envelope of amplitude variations of the radio wave.

It is important that the receiver should have an appropriate frequency-bandwidth in order to give an accurate representation of the amplitude variations in the radio wave. Fourier analysis shows that a radio pulse can be regarded as a group of sinusoidal waves with frequencies spread about the central radio frequency. If the pulse duration is T, then it can be shown that the sinusoidal components cover a frequency-bandwidth $\Delta\nu \approx 1/T$. Thus if the true pulse width is to be reproduced at the receiver output, the receiver amplifier must have uniform performance over the required bandwidth; for a 1 microsecond pulse a frequency bandwidth of the order of 1 megacycle/sec. is needed.

We will now formulate the factors which determine the signal power received by radar.

Let P = peak transmitter power,

G_T = power gain of transmitter aerial compared with an isotropic radiator,

G_R = power gain of receiver aerial compared with an isotropic aerial,

R = distance of observed object.

The power flux, p_1, at distance R from the transmitter is

$$p_1 = \frac{PG_T}{4\pi R^2}.$$

An object in this radiated field will reflect some of the radiated power back towards the receiver. The reflecting properties of the object, whether estimated theoretically or measured from radar observations, are usually expressed in terms of the Equivalent Echoing Area (or Scattering Cross-Section). This is the imaginary area normal to the radiation, such that if all the power incident on it was scattered uniformly in all directions it would give at the receiver the same power as the observed echo. Thus, if σ is the Equivalent Echoing Area of the target the power flux, p_2, at the receiver aerial is

$$p_2 = \left(\frac{\sigma}{4\pi R^2}\right) p_1 = \left(\frac{\sigma}{4\pi R^2}\right)\left(\frac{PG_T}{4\pi R^2}\right).$$

We have seen previously that the receiver aerial has an effective area equal to $G_R\lambda^2/4\pi$, where G_R is the power gain and λ the wave-length. Hence the available signal power at the receiver input (p) is equal to

$$p = \left(\frac{\sigma}{4\pi R^2}\right)\left(\frac{PG_T}{4\pi R^2}\right)\left(\frac{G_R\lambda^2}{4\pi}\right) = \frac{PG_TG_R\lambda^2\sigma}{(4\pi)^3R^4}. \qquad (4)$$

This is sometimes called the radar equation. Whether the signal p can be detected or not depends on the receiver sensitivity, which is discussed later in connection with the reception of noise radiation.

If we write $p_{\min}$ as the minimum detectable signal, and put $G_T = G_R = G$, since transmitter and receiver aerials are often identical, then we see that the maximum detection range $R_{\max}$ is given by

$$R_{\max} = \left[\frac{PG^2\lambda^2\sigma}{(4\pi)^3 p_{\min}}\right]^{\frac{1}{4}}. \qquad (5)$$

It is perhaps of interest to consider the reflection from a smooth perfectly reflecting sphere. If the radius, a, is greater than a few wave-lengths, the equivalent echoing area can easily be shown to be equal to πa^2. The solid angle w subtended by the sphere is therefore σ/R^2. From equation (4) it can be seen that the received signal power is proportional to σ/R^4 and hence to w/R^2. Thus, radar echo from a celestial object is not simply dependent on the solid angle, but is also inversely proportional to the square of the range.

If we consider a radio-frequency amplifier used for the reception of radio noise we again find that a wide bandwidth is an advantage. The mean power level of received radio noise increases with bandwidth. A given component of random fluctuation would thus be a smaller proportion of the mean power level when the bandwidth is wider. A more stable rectified output can therefore be obtained with a wide-band receiver.

The calibration of the radio amplifier is best achieved with the same type of input signal that is being investigated, so as to ensure that the valves are operating in similar conditions in both cases. Thus, a pulse signal generator should be used to calibrate a radar receiver, and a noise signal generator for a receiver used to observe extra-terrestrial noise.

When the directional characteristics of the aerial and the calibration of the receiver are known, it becomes possible to determine the power flux received from any source. Suppose the power flux is $p\Delta\nu$, where $\Delta\nu$ is the frequency bandwidth. This flux is usually measured in watts per sq. metre and $\Delta\nu$ in cycles per second. Hence p is expressed in units of watts/(sq. metre) (c./s. bandwidth). If radiation is

received from an extended source, the power flux $p\Delta\nu\,\Delta w$ is received from an element of solid angle Δw, the units then become watts/(sq. metre) (c./s. bandwidth) (steradian).*

Some workers prefer to express received radio-noise power in terms of equivalent black-body temperature, which is of course only possible when Δw is known. In a uniform temperature enclosure the power flux, according to the Rayleigh-Jeans formula, which applies at radio wave-lengths, is given by

$$\frac{8\pi kT}{\lambda^2}\Delta\nu,$$

where k is Boltzmann's constant and T the absolute temperature.

If $P\Delta\nu$ is the power flux per unit solid angle, we have

$$4\pi P\Delta\nu = \frac{8\pi kT}{\lambda^2}\Delta\nu,$$

so that

$$P = \frac{2kT}{\lambda^2}. \tag{6}$$

This formula may then be used to determine an equivalent black-body temperature T_e, when radio power flux $p\Delta\nu\,\Delta w$ over a region of solid angle Δw has been observed, by putting $p = 2kT_e/\lambda^2$. Equivalent temperature has the advantage of providing a simple unit to express, but it is apt to be misleading in significance if the source is not a temperature-limited phenomenon.

The sensitivity of a radio receiver is defined by its Noise Factor. If an ideal noiseless receiver is matched at its input to a resistor, then Nyquist's theorem shows that the available power at the receiver terminals due to thermal agitation in the resistor is $kT_0\Delta\nu$, where k is Boltzmann's constant and T_0 is the temperature of the resistor. $T_0 = 290$ deg. K. is usually taken as the standard value when comparing receivers. The noise generated in an actual receiver makes it behave as if there were an additional noise power $p_n\Delta\nu$ at the input terminals. The Noise Factor (N) of the receiver is defined as the ratio of the apparent input noise to the ideal input noise, so that

$$N = \frac{p_n + kT_0}{kT_0}. \tag{7}$$

An impression of receiver sensitivity may be obtained as follows. The value of kT_0 is 4×10^{-21} watts. Receiver noise factors vary from about 3 at metre wave-lengths to about 12 at cm. wave-lengths.

A further concept will now be considered because it is sometimes used by radio workers, namely the idea of aerial temperature. When an aerial is connected to the receiver we have instead of noise power $kT_0\Delta\nu$ from the resistance the noise received from the enclosure in which the aerial is placed. Suppose the aerial is in an enclosure at uniform temperature, T. By equation (6) the flux per unit solid angle is

$$p\Delta\nu\,\Delta w = \frac{2kT}{\lambda^2}\Delta\nu\,\Delta w.$$

The available received power is for one polarization and is therefore $\frac{1}{2}Ap\Delta\nu\,\Delta w$, where $A = \lambda^2 G/4\pi$ as given by equation (2). Hence the received power is

$$\frac{GkT}{4\pi}\Delta\nu\,\Delta w$$

for the direction in which the aerial power gain is G.

* Steradian = unit solid angle. (The surface of a sphere subtends 4π steradians at its centre.)

The available received power from all directions is

$$\frac{kT}{4\pi}\Delta\nu\int_{4\pi}G(\theta,\phi)\,dw=kT\Delta\nu.$$

Hence the aerial acts just like a resistor at temperature T.

If now we consider the aerial receiving extra-terrestrial noise we must substitute for T the effective black-body temperature T_e, which will however vary with direction. Thus the received noise becomes

$$\frac{kT}{4\pi}\Delta\nu\int_{4\pi}G(\theta,\phi)T_e(\theta,\phi)\,dw,$$

and it may be seen thus that the aerial behaves as if it had an effective uniform aerial temperature T_a given by

$$G\int_{4\pi}(\theta,\phi)T_e(\theta,\phi)\,dw=G\int_{4\pi}(\theta,\phi)T_a\,dw,$$

or

$$T_a=\frac{1}{4\pi}\int_{4\pi}G(\theta,\phi)T_e(\theta,\phi)\,dw. \tag{8}$$

The only advantage in using the idea T_a is that it is a simply expressed unit for indicating the integrated noise received, but it is apt to be misleading when the noise is of non-thermal origin.

3. *Radar Observation of Meteors*

3.1. *Experimental Investigations.*—Important advances in the study of meteors have recently been made by means of radar. The meteors themselves are in general far too small to give detectable radio reflections, but the ionization in the meteor trails which they produce at heights around 100 km. can be observed at appropriate wave-lengths. The ionospheric E layer occurs in a height region near 100 km. and it is therefore not surprising that the first indications of meteoric ionization were found during early investigations of E layer reflections. The ionization of the normal E layer is known to be controlled in a uniform manner by ultra-violet solar radiation. But there also exists an irregular ionization layer which may occur at night as well as during the day in the same region and which is known as the abnormal or sporadic E layer. Skellett (1932, 1935) suggested that meteors were an important agency in producing irregular ionization and with Schafer and Goodall (1932) he obtained experimental evidence of sudden increases in ionization occurring almost simultaneously with the passage of visually observed meteors. Many investigations have been made attempting to correlate abnormal E ionization with meteors, thunderstorms, barometric pressure, magnetic activity, and so on, but the work of Appleton and Naismith (1947) seems to show conclusively that in temperate latitudes meteoric ionization is a main cause, although the normal E ionization also has a controlling influence on the ionizability of the medium.

It is, however, another type of irregular ionization in this same region which has yielded striking contributions to astronomy, namely the observation of the intense localized bursts of ionization caused by individual meteors. With sufficiently high-power equipment these bursts of ionization can be observed at wave-lengths shorter than the critical wave-lengths of either the normal or abnormal E layers, that is, at wave-lengths which are readily transmitted through the layers.

The ionization bursts produce transient echoes rarely persisting for many seconds and the majority lasting only a fraction of a second.

These transient echoes were noted by Schafer and Goodall (1932) as a specific feature of the Leonid shower of 1931, but their general occurrence was first observed during 1932–33 by Appleton, Naismith and Ingram (1937). In subsequent work, notably by Appleton and Piddington (1938), Eckersley (1937, 1940), and Eckersley and Farmer (1945), information on various properties of the transient echoes was gradually accumulated. Following Skellett's suggestion of the meteoric origin of the abnormal E-layer ionization, both Appleton and Skellett were of the opinion that the echoes were due to meteors, but Eckersley was disinclined to this view. The evidence was not in fact conclusive, until the work of Hey and Stewart (1946, 1947) proved definitely that most of the transient echoes seen at wave-lengths around 5 metres must be due to reflections from meteor trails. The previous work had been carried out at wave-lengths greater than 10 metres, and as Appleton and Naismith (1947) subsequently demonstrated, there was a general parallelism between the phenomena of the bursts observed at these longer wave-lengths and the ionization of the abnormal E layer. The rate of occurrence of bursts showed diurnal and seasonal variations which could be explained in terms of a general distribution of meteoric dust in space, together with the influence of the normal E-layer ionization; visible meteor showers only became evident when of unusual intensity as, for example, during the 1946 Giacobinid shower. Only at shorter wave-lengths, such as 5 metres, could the majority of echoes be identified with meteor showers of the type recognised by visual means. The subsequent discussion will therefore be concerned most particularly with the work on wave-lengths around 5 metres, which has yielded valuable information on the characteristics of the major meteor showers.

Hey and Stewart (1946, 1947) carried out their investigation of the transient echoes with modified Army radar equipments, operating at 4–5 metres wave-length and with peak powers of about 150 kilowatts. One series of experiments was made with vertically-directed Yagi aerials, the combined transmitter and receiver power sensitivity pattern having a width of about 30°. A simultaneous visual watch during the 1946 Lyrid shower showed that visible meteors whose tracks passed across the radar beam were producing echoes. There were several times as many echoes occurring as visible meteors, but it was realized that meteors which did not give sufficient light for unaided visual detection might well produce sufficient ionization to give a radio echo. To prove that the echoes originated from meteors, Hey and Stewart made a detailed general comparison of the general properties of meteors with those of the echoes. For example, they found that the mean hourly rate of occurrence of echoes during the first half of 1946 showed very marked peaks corresponding to the two major showers during this period, namely the Quadrantids and Lyrids, with durations of one day for the Quadrantids and 3–4 days for the Lyrids, as would be expected. The height distribution of the echoes, 90 per cent occurring between 87 km. and 108 km. with a maximum occurrence at about 95 km., agreed well with the known heights of occurrence of meteors.

Experiments were also made in 1945 June–August with the Yagi aerials inclined to give a maximum at about 55° elevation. During the Perseid shower of 1945 August, an equipment was oriented so that any meteors which passed through the beam could be viewed perpendicular to the direction of travel. A peak in rate of

occurrence and a very marked increase in long duration echoes was observed on August 11–12, when the visible shower reached its peak.

The aspect sensitivity of the echoes was most clearly revealed by experiments made during 1945 June and July, when three equipments with inclined beams were oriented on different bearings. Pierce (1938, 1941) had previously pointed out that a meteor trail should be equivalent in radio reflection characteristics to a long cylinder, and the maximum echoing area would occur when the trail was viewed at right angles to its length. This hypothesis would explain why the range of a transient echo generally remained nearly constant throughout its duration, since the main reflection would be along the normal to the trail. The investigation made by Hey and Stewart, with three equipments on different bearings, verified Pierce's hypothesis. The diurnal variations in rate of occurrence of the echoes were entirely different for the three equipments, thus indicating that the echoing characteristics were sensitive to aspect. The different diurnal variations could be explained as follows: as the Earth revolves, the radar beams pointing in different directions become favourably oriented at right angles to the active meteor radiants at different times of the day. The times of occurrence of the peaks, in fact, made it possible to derive the positions of certain active radiants. This was done by determining the zones of possible radiant directions corresponding to the main peaks of diurnal rate at the different stations. The regions where these zones showed common intersections indicated the positions of active radiants. The accuracy of such a determination depends on the width of the aerial beam, and Hey and Stewart estimated that their errors in placing the radiant might be 10°.

During the 1946 Giacobinid shower, Hey, Parsons and Stewart (1947) succeeded in making the first radar determination of meteor velocities. They used a recording method in which the received echoes appeared as bright spots on a linear range trace, which was then photographed on a film moving at right angles to the trace at a speed of a few millimetres per second. A continuous range-time record of echoes was thus obtained. A number of the photographs showed a faint fast-moving echo prior to the formation of the main echo at right angles to the meteor trails. This faint echo was evidently caused by the ionization in the immediate vicinity of the approaching meteor. The tracks were consistent with uniform speed in a straight line, and the deduced velocities from 22 tracks gave a mean value of $22{\cdot}9 \pm 1{\cdot}3$ km. per sec., which was in good agreement with the theoretical geocentric velocity of the Giacobinids, namely 23·7 km. per sec.

These observations provided a clear link with the phenomenon of "whistling meteors" which Chamanlal and Venkataraman (1941) first observed at a wave-length of about 40 metres on receivers situated about 10 miles from a powerful continuous wave transmitter. Chamanlal and Venkataraman considered that these whistles were caused by beats between the directly-received wave from the transmitter and that reflected from the ionization in the vicinity of the approaching meteor. They thought that the decreasing pitch which they observed was due to retardation. The recordings of Hey and Stewart indicated, however, that the main changes of pitch could be explained by the rate of change of range of meteors moving with uniform speed.

A most comprehensive study of meteors by means of radar has been made by Lovell and his co-workers from 1946 onwards. The greater part of their observations has been made at 4·2 metres wave-length with transmitters of 150 kilowatts peak power. During 1946 June and August, Prentice, Lovell and Banwell

(1947) carried out a series of radio echo observations, some of them combined with a visual watch, with vertically-directed Yagi aerials. The combined radar and visual watch on several nights from July 29 to August 14 showed that good correlations could be obtained from echoes lasting more than 0·5 second. Their analysis of echo characteristics, as observed by vertically-directed beams, was in general agreement with that of Hey and Stewart (1947). They noted that the 1946 Perseid shower was accompanied by a marked increase in echoes of long duration, a result which Hey and Stewart had also observed for the 1945 Perseids.

For the Giacobinid shower of 1946, Lovell, Banwell and Clegg (1947) used an aerial system giving a narrow beam and mounted so as to be adjustable in bearing and elevation. The same aerial, which consisted of 5-Yagis, was used for both transmission and reception. The beamwidth was 28° in elevation and 13° in bearing, and the shower was observed by directing the beam at right angles to the radiant. A test to verify the aspect sensitivity of the meteor trails was made during the shower. They found that when the beam was directed towards the radiant the number of echoes dropped to about 4 per cent of the value when the beam was at right angles to the radiant. A simultaneous visual watch showed a similar proportion of correlations to that obtained previously during the Perseids, except that there was some increase in the correlations for short-lived echoes. A ciné film taken during the maximum activity of the shower showed the remarkable echo rate of 168 per minute. Within ± 5 minutes of the peak, the rate was down to 50 per minute and within ± 30 minutes it was down to 1 per minute. Subsequent experience with this apparatus showed that the rates of occurrence of echoes were similar to those of visually observed meteors. The conditions, of course, are different, but the narrow beam of the radar was counterbalanced by its greater sensitivity.

The narrow beam directional aerial was later used to determine meteor radiants by an ingenious method devised by Clegg (1948). The narrow beam is first directed at low elevation on a bearing due east. Meteor trails from a given radiant first become observable at right angles to the beam as the radiant passes due south. A consideration of the geometry of the trails (which are formed in the 100 km. height region) indicates that those which can give reflections at the time of transit of the radiant are at very long range, but as the radiant moves west the range diminishes. This characteristic sudden appearance of echoes at long range and subsequent decline of range enables showers to be identified and the right ascension of the radiant is determined by the time of transit. The declination of the radiant is found by rotating the beam to a new position towards the south. From the time taken for the radiant to move to a position at right angles to the new beam direction the declination of the radiant could be calculated. It was estimated that this method could place the average radiant within a few degrees.

Using this method of radiant determination, Lovell, Clegg and Hughes (1947) located a great belt of meteoric radiants, active during the summer months and observable only in daylight hours. During investigations of the η Aquarid shower at the beginning of 1947 May, they noticed the appearance of another radiant in the constellation of Pisces. In succeeding days this radiant became increasingly active. Subsequently the daylight activity developed with great rapidity and the radiants extended over a great belt stretching towards the Sun. The activity continued at a high rate until late August, when it finally disappeared.

The hourly rate at transit rarely fell below 20 and often exceeded 80. A few main features of the radiants were as follows. The radiant in Pisces first occurred in the region R.A. 20° to 32°, Dec. +20° to +30°, with an hourly rate about 20 to 25, and minor radiants preceding and following. In the later half of May there was confused activity but by the end of May active radiants had appeared at R.A. 45° to 55°, Dec. +25° to 35°, hourly rate 20 to 25, and R.A. 52° to 62°, Dec. +15°, hourly rate 20 to 40. In the latter half of June there appeared new active radiants near R.A. 80° to 85°, Dec. +20° to +30°, hourly rate 20 to 30, and R.A. 66° to 68°, Dec. +30° to +40°, hourly rate 20 to 45. The whole area between the main groups showed considerable activity. Observations during 1948 have closely resembled those of 1947 and indicate that the streams recur annually.

An interesting new method of determining meteor velocities was devised by Ellyett and Davies (1948), of the same research group, who made detailed measurements of the fluctuations of echo-amplitude. They related the fluctuations to the diffraction pattern expected by considering the Fresnel zones which would contribute to the reflection as the meteor trail passed through the region where the perpendicular from the station meets the trail. The zone widths of the successive maxima and minima could be determined theoretically and hence the velocities could be deduced. The method was first applied to the Geminid shower of 1947 December 11–13 and the Quadrantid shower of 1948 January 3–4. They found a mean geocentric velocity of 34·4 km./sec. (standard deviation 2·8 km./sec.) for the Geminids in excellent agreement with 34·7 km./sec. obtained by Whipple from photographic measurements of visible Geminid meteors. The Quadrantid velocities were more widely spread and several velocity groups appeared to be present.

At longer wave-lengths much higher rates of occurrence of echoes can be observed and, as mentioned previously, the work of Appleton and Naismith (1947) has shown that the type of echoes which can be associated with visual meteor streams become submerged in the high background rate. Lovell (1948) estimates that this transition takes place in the region of about 8 metres wave-length. Combined visual and radar observations of the Perseid shower at a wave-length of 9·2 metres have been described by Millman, McKinley and Burland (1948). They found that echoes correlated with visual meteors could be observed almost uniformly over a wide range of aspects of the meteor directions. They concluded that in addition to the echoes formed at right angles to the trail, there were localized concentrations of ionization which gave echoes for other aspects. On this basis they postulated discrete layers in the ionospheric region in which the meteors appear and which are more susceptible to ionization.

3.2. *Theoretical Estimation of Electron Densities in Meteor Trails.*—Only an outline of the most recent theoretical work on meteoric ionization can be given here. For a discussion of previous work reference should be made to the Physical Society *Report on Progress in Physics*, 1946–47.

The electron densities in meteor trails required to give the observed echoes have been calculated by Lovell (1947, 1948), and Lovell and Clegg (1948). They extended Blackett and Lovell's (1941) calculation of the intensity of reflection from a long narrow column of ionization whose diameter is small compared with the wave-length and deduced that the number α of electrons per cm. path is given by

$$\alpha = \sqrt{24\pi}\left(\frac{mc^2}{e^2}\right)\frac{1}{G}\sqrt{\left(\frac{pR^3}{P\lambda^3}\right)}, \qquad (9)$$

where e and m are the charge and mass of the electron,

G is the power gain of the aerial system compared with half-wave dipole,
P is the transmitted power,
R is the range,
p is the received power at the receiver input.

If the above theory is applicable to meteor trails one would expect that the ratio of received powers on different wave-lengths would be proportional to λ^3. As a test, Lovell and Clegg carried out a series of simultaneous observations on different wave-lengths, using simple half-wave dipole aerials. From observations on several wave-lengths between 1·4 m. and 8·3 m., they concluded that the received powers were proportional to λ^3 as indicated by the theory.

Equation (9) was then used to determine the electron densities in the trails, which they found to lie in the range 10^9 to 10^{12} electrons per cm. path. Simultaneous visual and radio observations of meteors made on a wave-length of 4·2 m. during the 1946 and 1947 Perseid showers indicated that a 5th magnitude meteor which is near the limit of naked-eye visibility produces about 2×10^{10} electrons per cm. path, and that a bright meteor of magnitude about +1 produces approximately 10^{12} electrons per cm. path.

The above results are in good agreement with the recent theories of meteoric ionization described by Herlofson (1948). According to Herlofson, the front surface of a meteor is bombarded by air molecules, the greater proportion of which are trapped in the meteor surface and give up their kinetic energy relative to the meteor as heat. This heat is sufficient to evaporate the meteor, and the evaporated atoms subsequently collide with air molecules, producing light and ionization. He estimates that the kinetic energy of a typical meteor is divided into heat, light and ionization in the ratios $10^4 : 10^2 : 1$. He deduces that a meteor of magnitude +1 will produce about 10^{12} electrons per cm. path, and one of magnitude +6 about 10^{10} electrons per cm. path, values which agree well with those derived by Lovell *et al.* from their radio-echo measurements.

Herlofson also concluded that meteor velocities would not decrease appreciably until the meteor is practically evaporated. Visual observational evidence on this is somewhat conflicting, but Hey, Parsons and Stewart (1947), in their radar measurements of the 1946 Giacobinid meteor velocities, noted particularly the absence of any marked retardation.

From the distribution of computed electron densities from radio echo observations of the 1946 Giacobinids, the 1946 Geminids, and the 1947 Quadrantids, Lovell *et al.* used Herlofson's results to calculate the distribution of mass among the meteors and deduced that the number of meteors of a given mass is inversely proportional to the mass.

The dependence of echo duration on diffusion rates was also estimated theoretically by Herlofson and satisfactory agreement was obtained with observations. A trail parallel to the Earth's magnetic field should diffuse more rapidly than one at right angles to the field, a result which Lovell confirmed by observation.

4. *Radar Observations of the Moon.*—Radar echoes from the Moon were obtained by the Engineering Department of the United States Signal Corps with apparatus described by Mofenson (1946).* Many workers had realized that the

* Note also Bay (1946) in the Addendum to the References ; this appears to be the first reported claim of radio reflections being observed from the Moon.

types of radar equipment used during the war were too insensitive to observe the Moon by a factor of about 5–10 times in detection range. The simplest method of overcoming this problem is to transmit very long pulses, and the echoes can then be received on a narrow bandwidth receiver without loss of peak power. Receiver noise, which limits receiver sensitivity, is proportional to frequency-bandwidth, so that by narrowing the bandwidth, receiver sensitivity is correspondingly increased. For example, the appropriate bandwidth for a 1 microsecond pulse is of the order of 1 Mc./s. For a $\frac{1}{100}$ sec. pulse a bandwidth of 100 c./s. could be used, and if the peak power is unaltered, the receiver sensitivity is effectively increased 10^4 times. This is the essential principle leading to the success of the first experiments by the United States Signal Corps. They transmitted pulses of $\frac{1}{4}$ second duration with 3 kilowatts peak power at a wave-length of 2·7 metres and used a receiver bandwidth of 57 c.p.s. The aerial system consisted of an array of 64 dipoles, with a wire-netting reflector, supported on a 100-ft. tower and directed horizontally, thus utilizing ground reflection to increase the gain. With this apparatus, reflections from the Moon could be observed near moonrise and moonset. Due to the relative velocities of the observer and the Moon the receiver had to be detuned about 300 c.p.s. from the frequency of the receiver to allow for the Doppler effect.

Such a method could be applied to a study of signal amplitude or of Doppler shift. To avoid possible ionospheric and atmospheric refraction it would be advisable to observe the Moon at higher angles of elevation. Alternatively, by working at low elevations and longer wave-lengths, ionospheric effects could be investigated. But the first stage would appear to be in any case to analyse the characteristics of the Moon reflection, and the various factors involved have been discussed in a recent paper by Grieg, Metzgar and Waer (1948). A disadvantage in having a long pulse is that the accuracy of range measurement and range resolution is correspondingly decreased. The rough configurations of the Moon's surface means that it cannot be regarded as a smooth sphere giving a reflection at the nearest point. To be effectively smooth the variations in surface height would have to be small compared with the wave-length. To study the radar echo in detail would require the use of a short pulse and thus wide bandwidth, and to obtain adequate radar sensitivity it would therefore be necessary to increase transmitted power and aerial gain very considerably over that available in present radar equipments.

5. *Galactic Radio Noise*

5.1. *Experimental Investigations.*—Galactic radio noise was discovered by Jansky (1932, 1933) when investigating atmospherics—the noise radiated from electrical discharges in the Earth's atmosphere—at a wave-length of about 15 metres. From results obtained during 1931 and 1932 he noted that there was an extra-terrestrial source of noise showing the periodicity of about 23 hours 56 minutes characteristic of sidereal phenomena. His aerial system had insufficient resolving power to give an accurate location but he found that the maximum was approximately in the direction of the galactic centre. Subsequent investigations (1935, 1937) of the diurnal variation led him to conclude that the general form could be explained by assuming a source distributed along the Milky Way. He suggested that the radiations might be received either directly from the stars or from an atmospheric source stimulated by stellar radiation. He had not, however, detected any radiation from the Sun. Noting the similarity of galactic noise to thermal agitation noise, he suggested that the source might be interstellar matter

(and quoted an electron temperature of 15,000 deg., an early estimate given by Eddington).

The next striking contribution to our knowledge of galactic radio noise was due to Reber (1940, 1942, 1944). His first experiment in 1937 was made at wave-lengths 9 cm. and 33 cm. in the expectation that the radiation would be of the black-body type and consequently greater at shorter radio wave-lengths. As no radiation was observed at these wave-lengths he next tried 1·85 metres. He used a parabolic reflector of diameter 9·5 metres mounted in the manner of a transit telescope. The aerial was adjustable in altitude to survey at various declinations while the rotation of the Earth traversed the beam in right ascension. He carried out a series of investigations at 1·85 metres wave-length and as his beamwidth was much narrower than that used by Jansky he was able to obtain more detail of the distribution of radio galactic noise. He estimates his beamwidth at 6° by 8° but with the given wave-length and aerial dimensions it could hardly have been less than 12°. The distribution of received noise which he obtained is given in Fig. 1 (*b*), which shows that the radiation is concentrated towards the galactic plane, with the maximum intensity in the direction of Sagittarius and secondary peaks in Cygnus and Cassiopeia. He was unable to obtain positive evidence of radiation from any individual prominent heavenly body, although he suspected that there might be a very weak signal from an extra-galactic nebula in Andromeda. During 1943 he also noted radiation from the Sun of the same order as that from Sagittarius; this observation is discussed in Section 6.1.

An investigation of galactic noise at 4·7 metres wave-length was made by Hey, Phillips and Parsons (1948). The aerial system comprised 4 horizontal Yagis, utilizing ground reflection to give a beam of width 13° by 14° with a maximum at a fixed elevation of 12½°. The principle of the method was as follows. At each sidereal hour the galactic noise was observed as the receiver was rotated in bearing through 360°. The directions traced out by the aerial axis when plotted on a projection of the celestial sphere formed a lattice of intersecting curves between declinations +60° and −30°, and the first step in analysis was to plot the observed noise on this lattice. In order to derive the distribution of galactic noise flux it was then necessary to correct for the effect of aerial beamwidth and side lobes. For a given position of the aerial the galactic noise observed at the receiver is given by

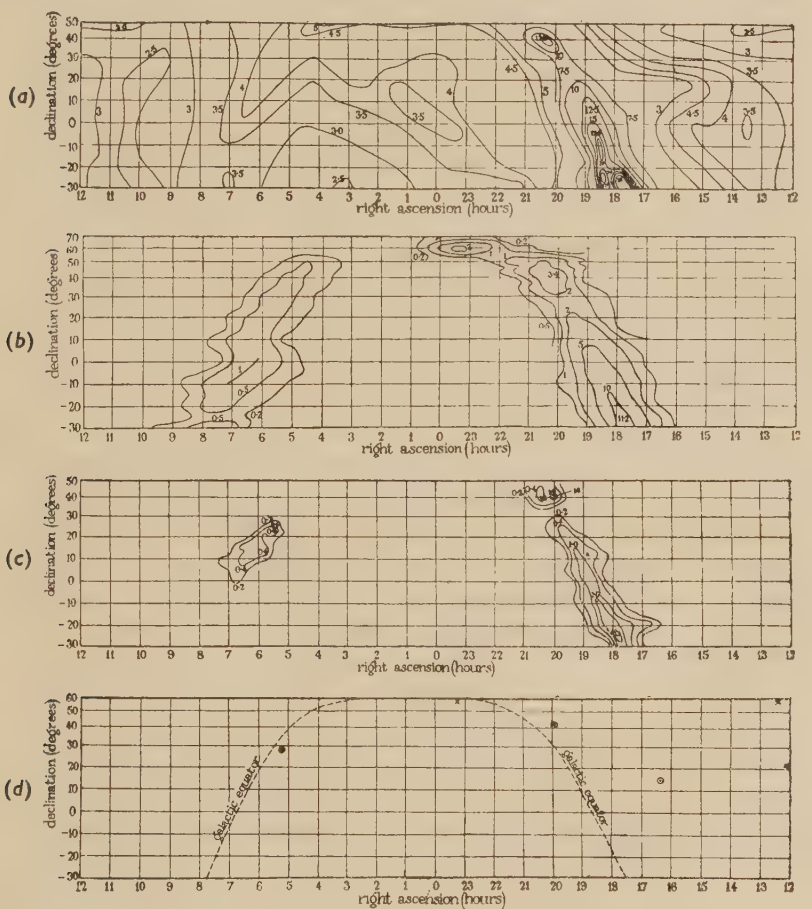
$$P = C \int_{4\pi} f(\rho, \delta) p(\rho, \delta)\, dw,$$

where $f(\rho, \delta)$ is the aerial sensitivity factor (see Section 2) and $p(\rho, \delta)\, dw$ is the galactic noise power flux from an element of solid angle dw, and C is a constant depending on the aerial and receiver sensitivities.

The aerial sensitivity pattern was measured by means of a lightweight oscillator suspended from a balloon. C was determined by comparing the received signal with that received on a single half-wave dipole, and by calibration of the receiver with a noise-signal generator.

A method of successive approximations was then applied, in order to derive from the plotted values of P the distribution $p(\rho, \delta)$ of galactic noise flux, and the results are shown in Fig. 1 (*a*). This distribution was compared with those of light intensity, of $H\alpha$ emission, and of particular types of stars, but only very general agreement was found. The closest correlation appeared to be with the distribution of novae and of highly-reddened stars which could be taken as an indication of the galactic structure as a whole.

Recently Reber (1948) has made a further examination of the galactic noise distribution at a wave-length of 0·625 metre, using again the paraboloid, of diameter 9·5 metres, for which at this wave-length he estimated the beamwidth at 3° by 3°. The maximum was again found to be in Sagittarius. The peak in Cygnus was observed to be split into two parts. There was again no conclusive evidence of radiation from the Andromeda nebula. The distribution he obtained is shown in Fig. 1 (*c*), and indicates that the radio noise is more closely confined to the region of the galactic plane at this wave-length.



* Fig. 1.—*Distribution of galactic radio noise obtained by :—*

(*a*) *Hey, Phillips and Parsons, at* $\lambda = 4{\cdot}7$ *m.*
Units 10^{-21} *watts/(sq. m.) (c./s. bandwidth) (steradian).*

(*b*) *Reber, at* $\lambda = 1{\cdot}85$ *m.*
Units 10^{-22} *watts/(sq. cm.) (Mc./s. bandwidth) (cir. deg.).*

(*c*) *Reber, at* $\lambda = 0{\cdot}625$ *m.*
Units 10^{-22} *watts/(sq. cm.) (Mc./s. bandwidth) (cir. deg.).*

(*d*) *Bolton* (⊙) *at* $\lambda = 3$ *m., Ryle and Smith* (×), *at* $\lambda = 3{\cdot}75$ *m., localized sources.*

[*Note.*—1 *steradian*=*approx.* 4177 *circular degrees. Hence, multiplying the contour values of* (*b*) *and* (*c*) *by* 4·177 *converts them to the same units as* (*a*).]

* This and other figures are drawn from the publications, to which reference is made, in some cases with changes of coordinates, and are consequently subject to inaccuracies in copying.

A new feature of the galactic radio noise was revealed by Hey, Phillips and Parsons (1946, 1948), who discovered irregular amplitude fluctuations, with period of the order of minutes or seconds, from the region of Cygnus. They concluded that there must be in this region a high-intensity variable source subtending a small angle, and they noticed the apparent similarity in fluctuation characteristics with the intense type of solar radio noise. They estimated the position of the source in early 1946 in the vicinity of R.A. $20^h\ 00^m$, Dec. $+43°$ with possible other areas within 8°, but their observations in late 1946 suggested a diffuse region near R.A. $20^h\ 30^m$, Dec. $+38°$. It may be of interest to note that these two regions are approximately the locations of the two Cygnus peaks in Reber's later investigation at 0·625 m., although he did not observe fluctuations at this wave-length.

A more accurate location of the source or sources of variations became desirable and the first attempt at this was made at a wave-length of 3 metres by Bolton and Stanley (1948), who applied the interference method which they had previously used for establishing that the intense solar radio noise originated from sunspots (see Section 6.1). This method gives an accurate location of single sources of angular width small compared with the angle between the maxima and minima of the interference pattern; but the method does not delineate the distribution of widely diffused sources. They obtained the location of the Cygnus variations as a source of less than 8′ angular width at R.A. $19^h\ 58^m\ 47^s \pm 10^s$, Dec. $+41°\ 41' \pm 7'$.

They found that the radiation consisted of both variable and steady components; the relative amplitude of the variable component decreased with decreasing wave-length and was not detected at $1\frac{1}{2}$ metres. No close correlation in the fluctuation amplitude curve with time was found even with wave-lengths as close as 3 metres and 3·5 metres. They noted that the position of the source did not coincide with any outstanding stellar object.

Later observations by Bolton (1948) revealed further sources of small dimensions and high intensity. The locations and intensities of point sources which they had obtained at 3 metres wave-length are given in Table I below, and they are marked on Fig. 1(*d*).

TABLE I

Approx. location	R.A.	Dec.	Intensity in watts/(sq. m.)(c./s.)	Angular width	Type
	h m	° ′			
1. Cygnus	19 59	+41 47	6×10^{-23}	< 8′	Variable
2. Taurus	5 13	+28	10^{-23}	<30′	Probably long period variable
3. Coma Berenices	12 04	+20 30	$1{\cdot}5 \times 10^{-23}$	<15′	Constant
4. Hercules	16 21	+15	2×10^{-24}	< 1°	...

Bolton noticed also a source near Centaurus and a weaker one which rose just before it, but precise location was not possible owing to this overlap. He also detected a weak source which rose just before Taurus.

Later, Ryle and Smith (1948) observed a further discrete source in Cassiopeia, a region in which Reber had first noted a minor peak. By means of their interferometer (see Section 6.1) operating at a wave-length of 3·75 m., they found that the localized source in Cassiopeia was more intense than that in Cygnus (for which

they determined the value 14×10^{-23} watts/sq. m. c.p.s.) but the fluctuations were smaller. A less intense but markedly variable source was also detected in Ursa Major. The angular diameters of the sources were less than 6′, the resolving power of the apparatus. They also investigated the polarization of the radiation and found it to be random.

Moxon (1946) attempted to find the manner in which the galactic noise flux varied with frequency by observations at wave-lengths of 1·5, 3·3 and 7·5 metres, which he also combined with those of Hey, Parsons and Phillips at 4·7 metres. He differentiated between the noise from the region of the galactic plane, which he concluded varied as $\lambda^{0.7}$, and that from regions away from the galactic plane which varied as $\lambda^{0.1}$. He considered that this might indicate a secondary noise source either of atmospheric or extra-galactic origin.

Herbstreit and Johler (1948) used a simpler method which is less liable to errors in calibration and estimation of aerial patterns, but which has the disadvantage of low directivity. With simple $\lambda/2$ dipoles at a height of $\lambda/4$ above ground at wave-lengths of 12 metres and 2·7 metres, they estimated that the noise power varied as $\lambda^{0.41}$.

5.2. *Theories of the Origin of Galactic Radio Noise.*—The first serious attempt to account for the observed intensity of galactic radio noise was made by Reber (1940). He suggested that the radiation originated from ionized interstellar hydrogen due to the free-free transitions of electrons in the fields of protons. At these wave-lengths it may be noted that the effect of the stimulated emission becomes important. Henyey and Keenan (1940) developed the theory more fully and determined the spectral distribution from optical wave-lengths up to the longest radio wave-lengths which can penetrate the ionosphere. Their equation of transfer of a ray in the Milky Way is:—

$$\frac{-dI_\nu}{ds} = (K_\nu + \sigma_\nu - \mu'_\nu)I_\nu - (K_\nu + K'_\nu)B_\nu,$$

where K_ν = absorption coefficient due to free-free transitions,
σ_ν = the coefficient of electron scattering,
K'_ν = absorption coefficient for bound-free transitions (which in this case produce only emission due to the high dilution of the exciting radiation),
μ'_ν = coefficient of stimulated emission,
B_ν = black-body emission corresponding to the electron temperature.

Integration gives

$$I_\nu = \frac{K_\nu + K'_\nu}{K_\nu + \sigma_\nu - \mu'_\nu} B_\nu(1 - e^{-\tau_\nu}),$$

where τ_ν, the "optical depth" is equal to

$$\int_s (\mu'_\nu - K_\nu - \sigma_\nu)\, ds.$$

By substituting appropriate values for the various coefficients and taking 10,000 deg. K. for the electron temperature, 16,000 parsecs for the thickness of the emitting layer, and electron and positive ion densities of 1 per c.c., they determined the spectral distribution which is shown in Fig. 2. They found that in the visual region the bound-free transitions predominate, but for wave-lengths about 20 microns they become negligible in comparison with the free-free transitions. The intensity then increases little with wave-length until it reaches a

maximum around 5 metres, when the optical depth $\tau_\nu > 1$. At longer wave-lengths the radiation then becomes black-body and, as the Rayleigh-Jeans formula indicates, falls off inversely as the square of the wave-length.

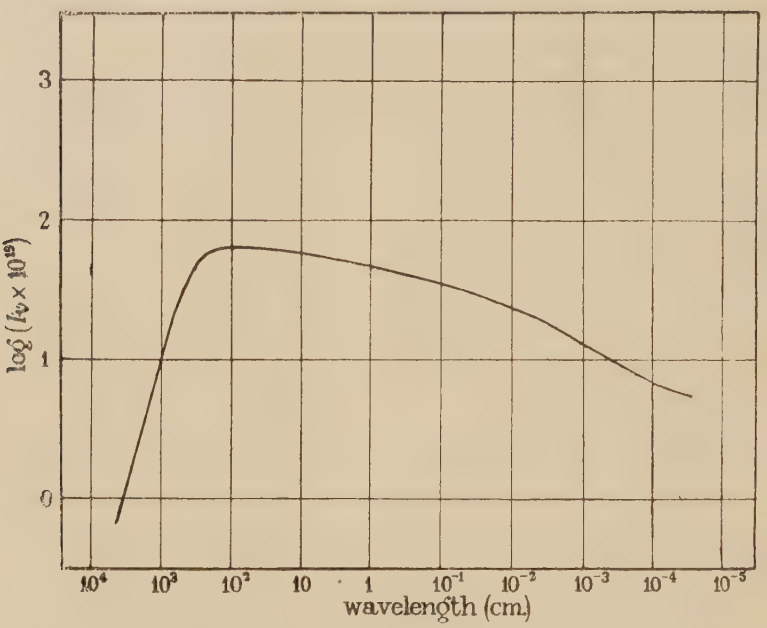


FIG. 2.—*Relation between intensity of galactic radiation from direction of Sagittarius and wave-length, computed by Henyey and Keenan.*
Unit of I_ν is ergs/(sec.) (kilocycle bandwidth) (sq. cm.) (sq. degree).
[*Multiply by approx.* $3{\cdot}3 \times 10^{-3}$ *to convert to watts/(sq. m.) (c./s. bandwidth) (steradian).*]

Other workers, for example, van de Hulst (1945) ,Townes (1947), have made similar analyses which are substantially in agreement with that of Henyey and Keenan (1940). All find that a reasonable fit with experimental observations could be obtained except for the longer radio wave-lengths, which present a serious discrepancy. It is only possible to explain the high intensities at the longer wave-lengths on this theory by assuming an electron temperature of 100,000 deg. to 200,000 deg. K. This may be illustrated by Table II, given by Townes (1947). The results refer to the region of maximum galactic noise and are expressed in terms of equivalent temperature T_e.

In the last two columns the electron density has been adjusted so as to give equality between the theoretical estimates and Reber's observations. It is interesting to see how well the experimental results at all wave-lengths can be brought into line by taking $T_e = 150{,}000$ deg. K.

The above calculations are, of course, based on simple assumptions of a uniform layer of ionized interstellar gas. Shklovsky (1947) pointed out that on the above theory of origin the sources of radio noise would in fact be concentrated in the ionized zones surrounding the hot stars. Hey, Phillips and Parsons (1948) also considered this suggestion and compared their galactic noise contour map with the observed distributions of O and B stars and of regions of $H\alpha$ emission, but without any conspicuous success.

In their earlier investigations, Jansky and Reber considered the idea that galactic noise might be due to radiation from the stars but rejected it because they

did not observe radio emission from the Sun. Since then, although it has become known that the Sun can emit very intense radio noise, the aggregate intensity from the stars would still be far too small to account for the observed intensity of galactic noise if the Sun can be regarded as an average star. Greenstein, Henyey and Keenan (1946) estimated that the observed galactic radio noise was 10^9 to 10^{12} times greater than would be expected on this hypothesis.

TABLE II

Observer	Wave-length metres	Maximum observed T_e	Maximum theoretical T_e assuming $n=0{\cdot}63$/c.c. $T=10{,}000$ deg. K.	Maximum theoretical T_e assuming $n=1{\cdot}1$/c.c. $T=150{,}000$ deg. K.
Dicke	0·01	(Negative Result)< 30	5	5
Reber	0·625	100–200	140	140
	1·85	1370	1370	1370
Hey, Phillips and Parsons	4·7	10,600	6000	9000
Jansky	16	92,000	10,000	84,000
Friis and Feldman	31	120,000	10,000	140,000

The observations of fluctuations in the Cygnus region by Hey, Phillips and Parsons, and the similarity of the fluctuations to those of intense solar noise, led them to suggest that some stars may be relatively enormously more powerful sources of radio noise than is the Sun, and that galactic radiation originates in this manner as well as from interstellar ionized hydrogen. However, the location of the discrete source in Cygnus by Bolton and Stanley (1948), and of other similar sources by Bolton (1948), and Ryle and Smith (1948), has so far only deepened the mystery, since the localized regions have not been identified with any particular stars or nebulae; further, as pointed out by Ryle and Smith (1948), the radiation from these sources does not show the circular polarization characteristic of the intense radio noise from sunspots.

Further information on the spectral distribution would be valuable in helping to elucidate the origin of galactic noise. Although experimental workers often achieve an accuracy of a few per cent in relative intensities at one frequency, it is by no means unusual to have possible errors of more than 50 per cent in determinations of absolute level. This leads to some difficulty in estimating the variation of intensity with frequency. If the galactic noise increased more rapidly with wave-length in the high intensity regions near the galactic plane than elsewhere, as Moxon (1946) claimed, then the high intensity regions would stand out from the background more prominently as the wave-length increases. The contour maps of distribution obtained by Reber at 0·625 m. and 1·85 m. and by Hey, Phillips and Parsons at 4·7 m. (see Fig. 1) all point to an opposite conclusion; as the wave-length increases the high intensity regions become less prominent in comparison with the low intensity regions.

An interesting possibility of spectral line emission has been suggested by van de Hulst (1945), namely that a hydrogen line at 21·2 cm. wave-length due to a

hyperfine-structure transition might be detectable. No observations at this wave-length have been reported as yet.

6. *Solar Radio Noise*

6.1. *Experimental Investigations.*—Radio-frequency noise from the Sun may be classified into two main types, namely radiation giving a substantially constant background level corresponding to the quiescent Sun, and intense radiation from solar disturbances. It has been found that sunspots and solar flares can often be associated with the intense radiations.

Occurrences of high level noise at the time of radio fadeouts were noted on short-wave radio equipments during the last sunspot maximum of 1936–1938. The first published reference appears to be that of Arakawa (1936), who stated that "on short waves high noise often accompanied sudden fades". Both Dellinger (1937), and Newton and Barton (1937), in their analyses of the association of radio-communication fadeouts and solar flares, mention that noise was often reported before or after a fadeout. The origin of the noise, however, was not known. Nakagami and Miya (1939) made approximate measurements of the angle of arrival of the noise on wave-lengths of 23 metres and 17 metres, but they concluded that the noise probably came from the ionospheric E layer.

In 1942 February, during the transit of a large sunspot across the Sun's disk, a very high level of radio noise caused severe interference on Army radar equipments operating on wave-lengths of 4–6 metres. This occurrence was investigated by Hey on behalf of the Army Operational Research Group and was described in reports in 1942 and 1945 which were restricted in circulation by war-time security regulations. It was found that receiving equipments in widely-separated parts of Great Britain had obtained approximate bearings on the source of interference and these indicated a direction within a few degrees of that of the Sun. At two equipments where measurements of the angle of elevation was also attempted, it was found that a telescope aimed in the indicated direction was always looking at the Sun within reasonable limits of error. Hey concluded that the noise consisted of high intensity electromagnetic radiations from the Sun associated with the sunspot activity.

Reber (1944) noticed during his observations of galactic radio noise during 1943 at a wave-length of 1·85 metres (see Section 5.1) that the Sun radiated an intensity approximately equal to that from Sagittarius, but did not then draw any conclusions about the significance of the magnitude.

Appleton (1945) drew attention to the earlier reports of hissing noises observed by amateurs during the 1936–37 maximum of the sunspot cycle. The noises were received during the daytime only and Appleton suggested that they were due to enhancements of solar radio emission of more than 10^4 times that corresponding to a black-body temperature of 6000 deg. for the visible Sun. Hey (1946) noted that the 1942 observations discussed above were about 10^5 times greater than the emission corresponding to a solar temperature of 6000 deg. K.

The great sunspot of 1946 February provided the opportunity for a more detailed study of the radio noise from the disturbed Sun. Appleton and Hey (1946) gave an account of the solar radio noise data obtained at several British research establishments and discussed its correlation with the available information of visual solar phenomena and the associated ionospheric and magnetic disturbances. On this occasion an almost continuous record of the power flux

of solar radio noise was made on a wave-length of 4·7 metres by the Army Operational Research Group. This revealed that there was a very high level of continuous emission associated with the sunspot. There were marked fluctuations in amplitude but the mean level reached a maximum near central meridian passage of the spot. Appleton and Hey also reported occasional sudden increases of the order of 10 to 100 times in power flux which occurred in certain cases almost simultaneously with the onset of solar flares and sudden ionospheric disturbances. The latter were indicated principally by short-wave radio-communication fadeouts (wave-lengths about 15–25 metres), or by increases of received atmospherics on very long waves (wave-lengths about 10,000 m.). Many of the intense solar flares are accompanied by some penetrating radiation, probably ultra-violet, which causes a strong enhancement of ionization in a region below the ionospheric E layer and known as the D layer. The comparatively high collision frequency of electrons in this region causes absorption of the short radio waves used for long-distance communication circuits. Very long waves, however, may be reflected from the lower boundary of the layer and the result is an increase in received atmospherics.

Some measurements were also made of the spectrum of the solar radio noise; although there were marked variations, the results indicated a peak intensity in the region of 5 metres wave-length with a sharp diminution at shorter wave-lengths and a much smaller decrease at longer wave-lengths until, as the ionospheric critical wave-length was reached, the solar radio noise emission was cut off from reaching the Earth. The highest intensity of power flux, about 2×10^{-17} watts/(sq. m.) (c./s. bandwidth), recorded at 4·7 metres wave-length, corresponds to an equivalent black-body temperature of the visible Sun of approximately 10^{10} deg. K.

Pawsey, Payne-Scott and McCready (1946) obtained a record of mean level of radio emission at 1·5 metres during 1945 October and showed there was a rough correlation with sunspot area. The first attempt to measure the diameter of the radiating source was made by Ryle and Vonberg (1946). They used a method analogous to Michelson's method for determining stellar diameters. At a wave-length $\lambda = 1{\cdot}7$ metres they used two aerials spaced at a distance $d = 140\lambda$ to give a multi-lobe interference pattern. The angle between successive maxima would therefore be given by $\sin\theta = \frac{1}{140}$, hence $\theta = 24'$. If the radiation from the Sun, as it moved across the interference pattern, came from a source of small diameter compared with the spacing of the maxima and minima, the amplitude of the received noise would vary correspondingly. For increasing diameter of source the ratio of maximum to minimum in the received intensities would become less. It was thus possible to obtain an estimate of source diameter, and Ryle and Vonberg concluded that the source subtended an angle less than 10′. A similar experiment confirming that the radio noise came from the immediate vicinity of the sunspot was made by Pawsey, Payne-Scott and McCready (1947), who utilized the interference pattern of an aerial system situated on a cliff overlooking the sea. The pattern is due in this case to interference between radio waves received directly and those reflected from the sea and is thus analogous to Lloyd's mirror interference fringes. A wave-length of 1·5 metres was used and the highest equipment was at a height of 400 ft., corresponding to a separation of 163λ between the aerial and its image. The ratios of maximum to minimum intensities which they measured always indicated that the radio noise came from the vicinity of

visible sunspot groups and was of the same order of width. It may be noted that the method of Ryle and Vonberg has the advantage that by using a horizontal spacing they could make observations on a source at high elevation, whilst Pawsey, Payne-Scott and McCready were restricted to low elevations, where the results might be liable to variable refractive effects in the Earth's atmosphere.

A more detailed description of the experimental methods of Ryle and Vonberg was given in a later paper (1948) and their technique for recording radio noise intensity is of special interest. Straight recording of the amplifier output requires apparatus of very stable performance if high accuracy is to be achieved. Both the receiver noise level and the amplifier gain may fluctuate. Dicke and Beringer (1946), whose results on micro-wave radiation from the Sun are discussed later, used a switching method in which the receiver input was alternately switched from the aerial to a generator of a standard signal. This effectively eliminates the effect of variations of receiver noise, since it is the difference between the two inputs which is now recorded. Ryle and Vonberg carried the method a step further. The amplifier output was made to operate a servo-mechanism which controlled the standard noise-signal generator to equalize its input to the receiver with that from the aerial. Their method is thus continuously self-calibrating, and except for second-order effect on servo-mechanism response, does not depend on either receiver noise or amplification factor.

The polarization of the solar radio noise associated with sunspots was first measured independently by several workers during the passage of the great sunspot towards the end of 1946 July. Martyn (1946) made observations at 1·5 metres wave-length and on 1946 July 26 just as the spot group was approaching central meridian passage the radiation was found to be circularly polarized in the right-handed sense, but three days later after the group had passed central meridian passage the polarization was reversed. Appleton and Hey (1946) also found that at a wave-length of 3·5 metres the radiation on 1946 July 27 and 28 was circularly polarized in the left-handed sense. Ryle and Vonberg (1946) reported that at 1·7 metres wave-length the radio noise received during 1946 July 27–August 3 was circularly polarized in the left-handed sense. Between August 3–7 the degree of polarization diminished, and on August 8 had changed to right-handed polarization. Further observations of circular polarization reported by Ryle and Vonberg (1948) are mentioned later.

The amplitude characteristics of solar noise have now been discussed in numerous communications. Pawsey, Payne-Scott and McCready (1946, 1947) and Allen (1947) investigated the correlation of mean level of solar radio noise at 1·5 metres wave-length over periods of about 6 months, and demonstrated the general relationship between solar radio noise and sunspots. The solar noise intensity gave a better correlation with sunspot area than with sunspot number. It was evident, as Appleton and Hey (1946) had observed, that there was no strict proportionality between sunspot area and noise flux. All that can be said at present is that the larger spots produce the most intense noise. The continuous emission from spots is very variable in character, sometimes being comparatively steady and at other times showing continual rapid fluctuations. It has been pointed out by Appleton and Hey (1946), Allen (1947) and others that active spots show a sharp maximum of intensity of radio noise when they are within 1 or 2 days of central meridian passage, thus indicating that the sunspot noise is emitted in a fairly sharp beam approximately normal to the spot.

As Appleton and Hey (1946) showed, certain very large bursts of solar radio noise can be associated with solar flares. There is no simple proportionality with flare intensity, but the greater the flare intensity the greater the probability of an associated burst, as a recent analysis by Hey, Parsons and Phillips (1948) has demonstrated. They also found that the bursts associated with flares do not appear to show the marked directional properties of sunspot noise, for no striking peak is apparent in the proportion of coincidences between bursts and flares for flares which occur near the Sun's central meridian. Some confusion has existed over the meaning different workers have given to the words "burst" and "outburst". Some workers (Allen, 1947, for example) have referred to the large bursts probably correlated with flares as "outbursts", and have referred to any other rapid fluctuations in level as "bursts". However, it is very difficult to make the distinction clearly defined. Others (Hey, Parsons and Phillips, for example) have classified all bursts by their amplitude, and the term "outburst" is used simply to indicate the highest magnitude of bursts. When there is a high, rapidly fluctuating mean level, due to a sunspot, the emission can have the appearance of a continual series of bursts; in such circumstances it is not permissible to associate bursts with flares except for bursts of large amplitude relative to the average fluctuation level.

Large bursts, or outbursts, can generally be detected over a wide range of wave-lengths, and Payne-Scott, Yabsley and Bolton (1947) have discussed the relative times of arrival of bursts at different wave-lengths. From observations on wave-lengths of 1·5, 4 and 5 metres, they found that the majority of associated bursts occurred in that order with a time delay of a few seconds between them. They also reported instances of longer delays of several minutes between the different wave-lengths. They interpreted the successive delays between the onsets as being related to a corpuscular solar emission, the radiation originating as the corpuscular emission reached different levels in the solar atmosphere. The electron density which would permit the escape of radio waves is smaller for the longer radio wave-lengths. Thus, one would expect shorter wave-lengths would be emitted first. From their results they derived corpuscular velocities of 500–750 km./sec. Hey, Phillips and Parsons (1947) independently came to a similar conclusion about the delays of several minutes which they had found between the onset of enhanced D-layer ionization and large solar radio bursts. They observed the onset of the D-layer absorption by the fall of received galactic noise at a wave-length of about 12 metres. (It may be added here that these workers had not found any marked time differences between different radio wave-lengths.)

The information on the spectrum of either the continuous radio noise associated with sunspots or the bursts associated with solar flares is very incomplete. No suitable apparatus has been devised for obtaining an instantaneous spectrum, and so far all measurements have been based on an initial choice of fixed wave-lengths for observation. It is probable that panoramic receivers sweeping over a wide band of wave-lengths will be used in future experiments but such receivers involve a loss of sensitivity. In general it appears that both types of solar radio noise disturbance give the strongest intensities at wave-lengths of several metres. Hey, Phillips and Parsons (1948) have described measurements at several wave-lengths between 1·5 metres and 12 metres and they found the maximum intensity first at 2 metres and then 2 hours later at about 4 metres. Ryle and Vonberg (1948) obtained daily the ratio of the mean intensities of radio noise at wave-lengths of

1·7 metres and 3·75 metres from 1946 December to 1947 July; they concluded that the long-term average of equivalent temperature ratio was proportional to the square of the ratio of the wave-lengths, but there were considerable variations. Schulkin *et al.* (1948) have recently observed a large solar noise burst at several wave-lengths extending between the limits of 3 cm. and 12 metres. Exceptionally, large bursts may occur on very short wave-lengths only. An example has been given by Lehany and Yabsley (1948), who recorded a large burst on 0·25 m. and 0·50 m. but no corresponding burst on wave-lengths of 1·5 metres or more. Covington (1948) has recently given an account of bursts on a wave-length of 10·7 cm.; in the majority of cases the solar noise bursts at 10·7 cm. could be associated with ionospheric disturbances, causing short-wave fadeouts, which may be taken as an index of solar flare activity.

Before discussing further the solar noise observations on very short wave-lengths, we will consider the thermal radiation from the quiescent Sun, because it was at centimetric waves that the detection of thermal radiation at radio wave-lengths was first reported. From Section 2 we see that the power flux radiated from a black-body source at temperature T which subtends a solid angle Δw is given by

$$\frac{2kT}{\lambda^2}\Delta\nu \,.\, \Delta w$$

(where k is Boltzmann's constant, λ is the wave-length and $\Delta\nu$ is the frequency bandwidth). From this it would appear that the noise power flux would be inversely proportional to the square of the wave-length. However, as Martyn (1947) first pointed out, the thermal radiation at radio wave-lengths originates in the solar atmosphere and would depend on the electron temperature at the level at which the solar atmosphere is opaque to radio waves, and this would vary with wave-length.

The first experimental observation of the thermal solar radio noise from the quiescent Sun was made by Southworth in 1942 October, at a wave-length of 3·2 cm., and he first estimated the effective solar temperature at 6000 deg. K. but later corrected this to 18,000 deg. K. Security regulations limited his 1942 report to a restricted circulation. In 1945 he published details of these and other results obtained at wave-lengths between 1 cm. and 10 cm. Dicke and Beringer (1946) applied their switching technique at 1·25 cm. wave-length and deduced temperatures of 11,000 deg. K. for the Sun. (They also found radiation from the Moon corresponding to a temperature of 292 deg. K.) Covington (1948) at 10·7 cm. wave-length obtained the value 79,000 deg. K. for the effective solar temperature. Covington's record of mean level in terms of effective aerial temperature is shown in Fig. 3. This indicates a fairly good general correlation at this wave-length with sunspot numbers. These results emphasize the necessity for a long series of observations when determining quiet Sun temperature in order to distinguish the noise associated with solar activity.

At wave-lengths of a metre or more, some difficulty in estimating the solar radio noise is caused by the relative increase in galactic noise level, together with the difficulty of obtaining a narrow enough beam to avoid receiving galactic noise over a wide region. The interference methods used by Ryle and Vonberg, and by Pawsey, Payne-Scott and McCready, overcame this difficulty. Except for several localized sources it is possible to regard the galactic noise as an extended source which consequently does not produce an interference pattern response. The

method thus distinguishes a localized source from the general background of galactic noise. Pawsey (1946), in an analysis of daily observations at a wave-length of 1·5 metres, found that the minimum effective temperature was in the region of $0{\cdot}6 \times 10^6$ to $1{\cdot}2 \times 10^6$ deg. K.

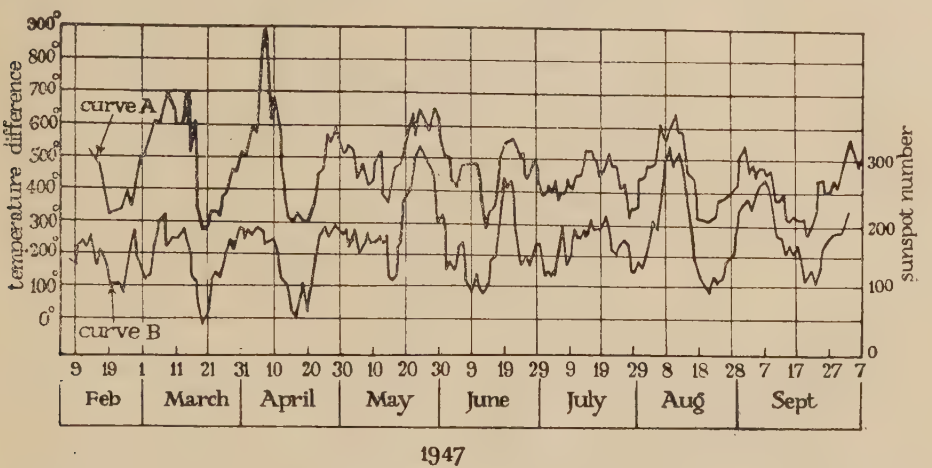


FIG. 3.—*Curve A*: *Daily variations of solar noise at* $\lambda = 10{\cdot}7$ *cm., observed by Covington, in units of effective aerial temperature.*
Curve B: *American relative sunspot numbers.*

Eclipse observations are particularly interesting because they give an indication of the region of the solar disk which is producing the solar noise. Martyn (1947) predicted theoretically that there would be a limb-brightening effect in the radiation from the quiescent Sun at centimetre wave-lengths. Several sets of observations were made during the partial eclipse of 1946 November 23. At a wave-length of 1·85 metres, Reber (1946) found that the reduction of received power was approximately equal to the proportion of the Sun's disk obscured. At 10·7 cm., Covington (1947, 1948) observed a 9 per cent decrease of solar noise occurring 3 minutes before first contact when the Moon's edge was 1·05 times the Sun's radius from the centre of the Sun. He notes that the Mt. Wilson Observatory records indicate an extensive band of prominences off the western limb and this initial reduction of solar noise occurred just as they were obscured. A further sharp fall of 25 per cent occurred as a spotted area, covering 2·2 per cent of the solar disk, was obscured. Covington's recordings and eclipse data are shown in Fig. 4. Sander (1947) also made observations at 3·2 cm. wave-length, and found that the graph of received noise power against time indicated that most probably the sources of radiation were located on the circumference of the Sun's disk, but that the results did not warrant a definite conclusion.

6.2. *Theories of the Origin of Solar Radio Noise.*—Before attempting to comment on the varied theories put forward to explain the origin of solar radio noise, a brief discussion will be given of certain relationships which apply to the propagation of electromagnetic waves in ionized regions such as the ionosphere and the solar atmosphere. Total reflection of a radio wave occurs when the refractive index becomes zero, and if there is no magnetic field this occurs when $f^2 = Ne^2/\pi m$, where f is the wave frequency, N is the electron density, e the electron charge in e.s. units and m the electron mass. Thus the condition for a wave to pass through an ionospheric medium is such that $f^2 > Ne^2/\pi m$.

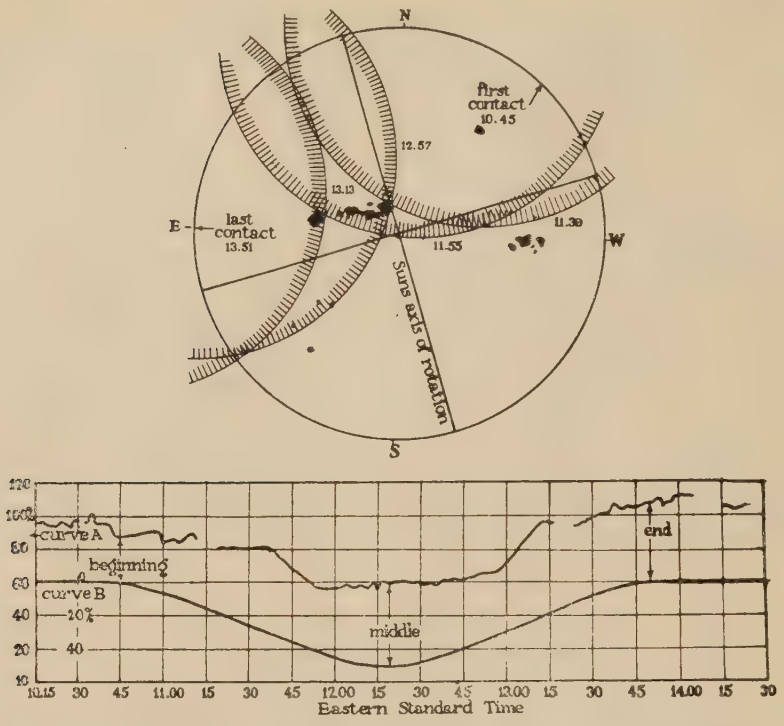


FIG. 4.—*Curve A*: *Observation of solar radio noise at* $\lambda = 10{\cdot}7$ *cm. by Covington during the partial eclipse of* 1946 *November* 23.

Curve B: *Eclipsed area of the Sun.*

Above: *Eclipse data from Dominion Observatory, Canada.*

If there is a magnetic field the conditions become more complex. Consider first a free electron having a component of velocity perpendicular to a magnetic field H (gauss). Such an electron would gyrate about the magnetic field with frequency $f_H = He/2\pi mc$, which is known as the gyro-frequency.

If an electromagnetic wave of frequency f is incident on an ionized gas in which there is a magnetic field, Appleton's magneto-ionic theory showed that the wave is split up into two components circularly polarized in opposite directions. The wave with the electric vector rotating in the same direction as that of the free gyration of the electrons is called the "extraordinary" wave, and the one circularly polarized in the opposite direction is the "ordinary" wave. The limiting conditions for transmission of these waves, which are most commonly accepted, are summarized in Table III below.

TABLE III

(*a*) *Direction of radio wave and field not the same*

(1) *Frequency* $(f) > $ *Gyro-frequency* (f_H)

ordinary wave, $f^2 > Ne^2/\pi m$

extraordinary wave, $f(f-f_H) > Ne^2/\pi m$

(2) $f < f_H$

ordinary wave, $f^2 > Ne^2/\pi m$

extraordinary wave, $f(f+f_H) > Ne^2/\pi m$

(*b*) *Direction of radio wave and field the same*

ordinary wave, $f(f+f_H) > Ne^2/\pi m$

extraordinary wave, $f(f-f_H) > Ne^2/\pi m$

(*a*) *Radio Noise from the Quiescent Sun.*—The origin of the radio noise from the quiescent Sun will first be discussed, since the theory given by Martyn (1947, 1948) is at present almost generally accepted. Our knowledge of the mechanism of generation of the intense noise is much less certain, and theories are more varied and speculative.

In his theory of the radio emission from the quiet Sun, Martyn considered first the absorption of a radio wave entering the solar atmosphere. Applications of Kirchhoff's Law and a knowledge of the absorption and the temperature will then indicate the emission intensity. At very short wave-lengths a radio wave travelling towards the Sun would penetrate to comparatively densely-absorbing regions without much deviation. In this case, Milne's criterion that the radiation comes from an average optical depth $\tau = 1$, where $\tau = \int K\,dS$, K being the absorption coefficient and dS the element of path, can be applied. At long wave-lengths the electron density in outer regions of the solar atmosphere is sufficient to reflect radio waves in a similar manner to terrestrial ionospheric reflection. In this case the maximum absorption occurs in the strongly-deviating region where the refractive index approaches zero. To find the emission, the total absorptive power in this region must be determined, since the medium will not be a full radiator. Martyn used the results of the classical applications of Maxwell's equation to electron atmospheres, and took into account the effect of the solar magnetic field on the basis of Appleton's magneto-ionic theory. One of the principal consequences of the magnetic field (when comparatively small as in the case of the Sun's general field) is to cause the refractive index of the extraordinary wave to fall to zero at lower electron densities and therefore in higher regions of the solar atmosphere than when there is no magnetic field. The estimated data used by Martyn for electron temperature T, electron density N, and collision frequency ν, are shown in Fig 5A. The polar value of the Sun's magnetic field was taken as 50 gauss.

Martyn then calculates the effective temperature over the solar disk for different wave-lengths. The results for the ordinary wave are shown in Fig 5B

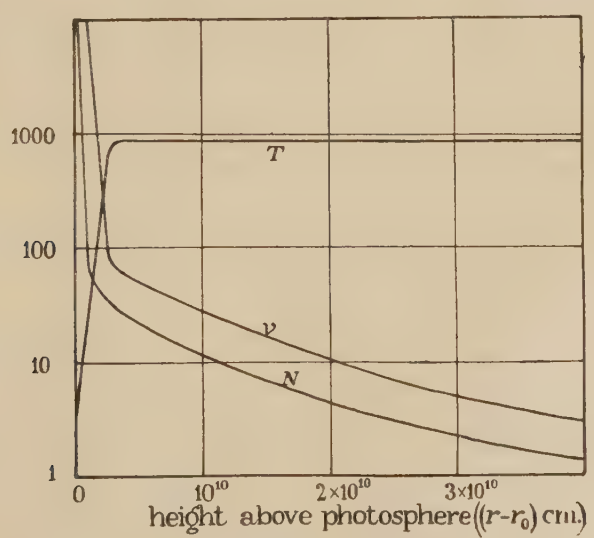


FIG. 5A.—*Solar data used by Martyn.*
N = distribution of electron densities (number of electrons/c.c. × 10⁻⁷).
ν = electron collision frequency (collisions/sec.).
T = temperature (deg. K. × 10⁻³).

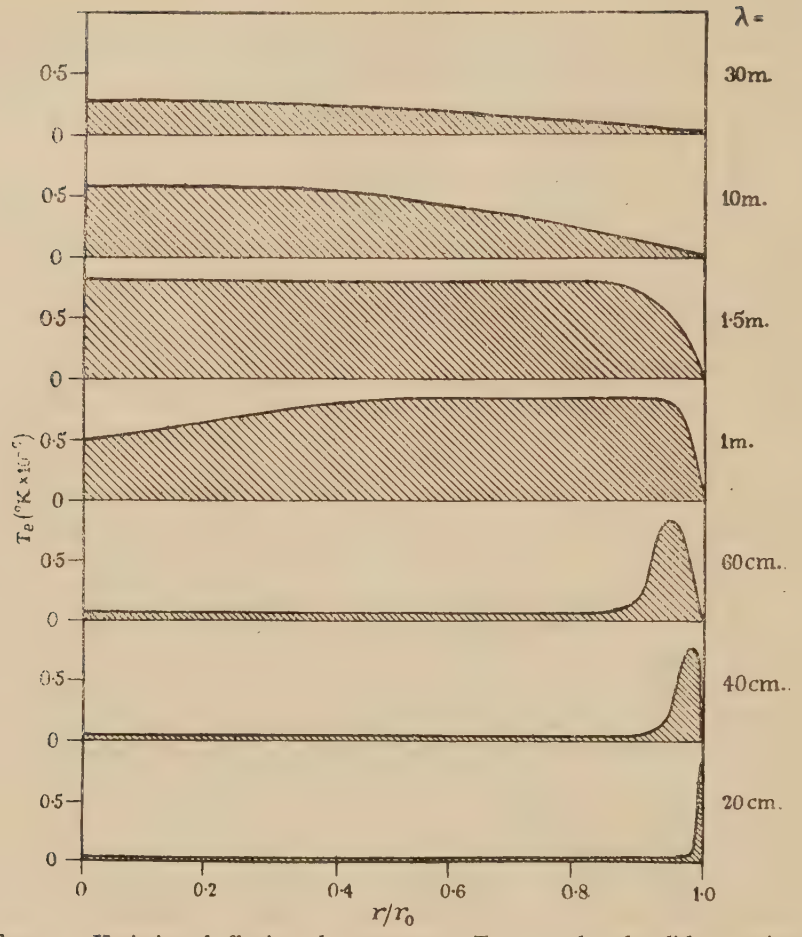


FIG. 5B.—*Variation of effective solar temperature T_e across the solar disk at various wave-lengths, deduced by Martyn ($r=r_0$ at limb).*

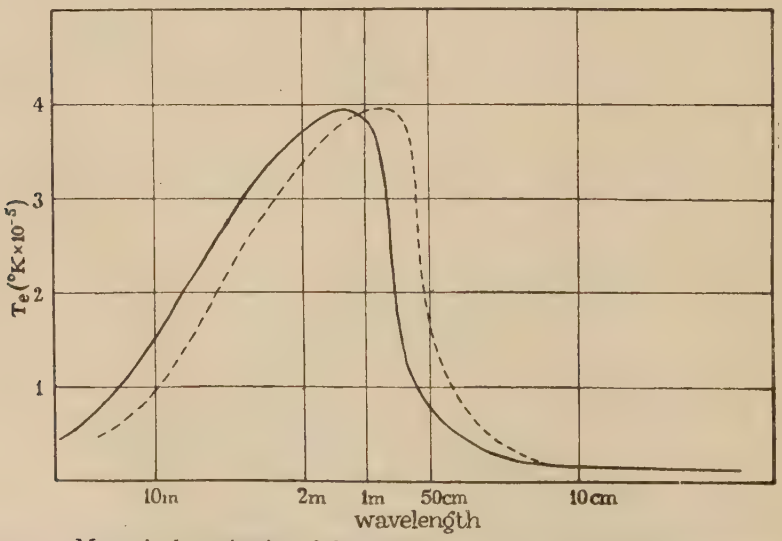


FIG. 5C.—*Martyn's determination of the effective temperature of the Sun considered as a full radiator, in the radio spectrum, for the ordinary (————) and extraordinary (– – – –) components. The total emission at wave-length λ is proportional to* $[T_e\,(ord.)+T_e\,(extraord.)]\times\lambda^{-2}$.

(r_0 is of the order of the solar radius but is not precisely defined). At wave-lengths of about 1 metre the disk is almost uniformly bright and the radiation is determined by the coronal electron temperature which is of the order of a million degrees. At shorter wave-lengths the radiation from the centre of the disk emanates from the chromosphere which is at a much lower electron temperature; but the emission from the limb still comes from the corona, and hence would result in a limb-brightening effect. The integrated effective temperature of the whole Sun, as calculated by Martyn, is shown in Fig. 5c. It may be noted that the different intensities of the ordinary and extraordinary radiation would result in circular polarization, which would be opposite in sense for the northern and southern solar hemispheres. If one hemisphere of the quiescent Sun alone could be observed, information on the Sun's magnetic field intensity could be derived. The tilt of the Sun's axis might be sufficient for the effect to be observed. Alternatively, observations could be made at eclipses. It will be seen that the experimental determinations of the intensity of quiescent radiation, given by Southworth (1945), Dicke and Beringer (1946), Pawsey (1946), and Covington (1948), and discussed in the previous section, agree satisfactorily with the values deduced by Martyn. The eclipse observations of Covington (1947, 1948) and Sander (1947) also suggested the possibility of a limb-brightening effect at centimetric wave-lengths.

Martyn finally added a note to show that although he has used a classical treatment, the correspondence principle should apply, since $h\nu \ll kT$, and the results should be almost identical with those given by quantum treatment. He discussed the radio emission arising from the free-free transitions of electrons in the field of protons and demonstrated that when the stimulated emission is taken into account the treatment leads to results almost the same as those obtained by the classical methods.

Calculations based on the quantum mechanical approach have been given by Unsöld (1947) and by Waldmeier and Müller (1948). Similar results were derived in both papers. Those from Unsöld's paper are shown in Fig. 6, and are seen to have the same general form as those derived by Martyn.

(*b*) *Theories of Solar Radio Noise Disturbances.*—As mentioned previously, there is as yet no generally accepted theory of the origin of the intense radio noise associated with solar disturbances, such as sunspots and flares. It appears very probable that the magnetic field of the sunspot has an important role, and measurements of polarization of the sunspot noise have shown it to be circular, as one would expect from magneto-ionic theory. No comprehensive account of the relation between the sense of the polarization and the direction of magnetic field has yet been given. Ryle and Vonberg (1948) stated that of 16 observations in which the source region was estimated, 9 corresponded to the polarization of the ordinary wave, 3 to the extraordinary wave and 4 were inconclusive.

A theory of the origin of radio waves from sunspots given by Kiepenheuer (1946) was based on the emission due to electrons with thermal velocities rotating in circular orbits in the magnetic field of spots. The frequency of rotation of the electrons is given by the gyro-frequency $f_H = He/2\pi mc$, which gives $f_H = 2{\cdot}8H$ in Mc./s., or $\lambda_H = 107/H$ in metres, where H is the field strength in gauss. Classical theory shows that an electron rotating with velocity V in an orbit will radiate, and that the field strength E at a distance r in the direction of the magnetic field is given by

$$E = \frac{e^2 VH}{mrc^3}.$$

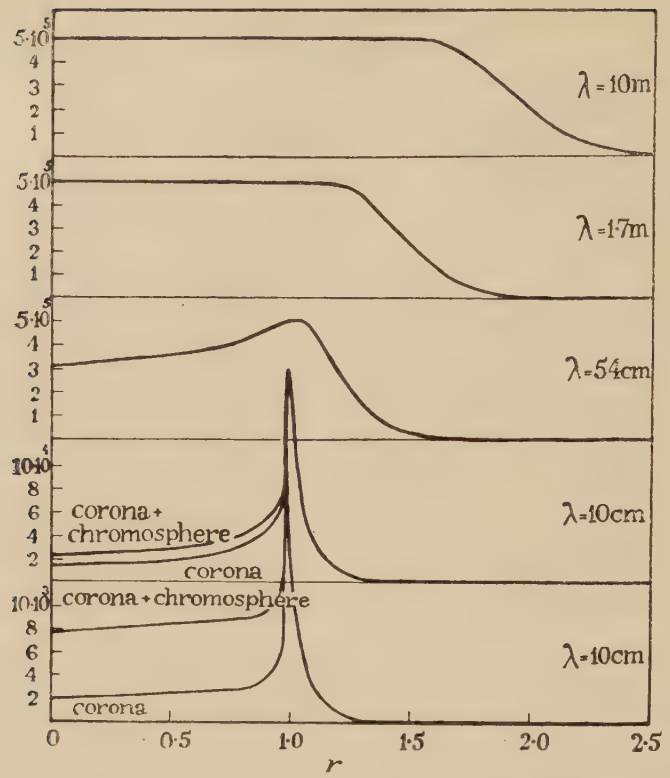


FIG. 6.—*Variation of effective solar temperature over the Sun's disk at different wave-lengths, deduced by Unsöld. r is measured in units of the Sun's radius.*

Assuming that the sunspot radio noise originates from a region in the inner corona of area 10^{-3} that of the Sun's disk and an electron temperature of a million degrees, Kiepenheuer calculated that the intensity of metre waves received at the Earth would be of the order of 10^4 times that from the Sun considered as a black body at 6000 deg. K. Kiepenheuer only considered emission, and his calculation is therefore invalidated by neglecting absorption processes.

A more thorough analysis based on the hypothesis of gyro-magnetic origin of sunspot radio noise has been given by Denisse (1947). He examined the derivation of the equations for the propagation of radio waves in an ionized atmosphere in the presence of a magnetic field, and took into account the spread of emitted frequencies due to both collisions and the Doppler effect. He found that the radiation from a region where the magnetic field of the spot is of the right order (for example, $H = 100$ gauss would correspond to gyro-magnetic radiation of wave-length of about 1 metre) could not escape owing to re-absorption, unless the gradient of the magnetic field is very high. He considered, however, that sufficiently high magnetic field gradients can occur, particularly during the development of a spot. He calculated that, under favourable conditions of high magnetic field gradient and assuming an electron temperature of 10^5 deg. K., radio noise of the order of 10^{-19} watts/(sq. m.) (c./s.) in power flux (equivalent to about 10^6 times the thermal radiation of the Sun at 6000 deg. K.) would be emitted.

The idea that the solar noise could arise from the free gyration of electrons at temperatures of 10^6 deg. K. or less in magnetic fields has been criticized byMartyn

(1947), Unsöld (1947) and Giovanelli (1948) on the grounds that it is difficult to see how electron motions which are thermal in origin could produce radiation exceeding that from a black body. This would appear, however, to require some detailed proof, because the imposition of a magnetic field introduces an ordered motion with a special frequency of emission. However, the contention that gyromagnetic radiation is limited by full radiation corresponding to the electron temperature has led many to reject such a mode of origin. There have been two distinct lines of approach: one based on special types of oscillations which do not involve very high temperatures; and the other assuming that extremely high electron temperatures, of the order of 10^{10} deg. K., actually exist in certain regions of the solar atmosphere. In this latter case it becomes of course necessary to postulate a mechanism of origin of such high temperatures and to account for their non-observation by visual means.

As an example of the first method of approach, Martyn (1947) suggested that the intense radio waves are produced by electron oscillations in ionized gases, and he referred to a derivation by J. J .Thomson (1931) that an electron gas would have a natural period T of oscillation given by $T=\sqrt{(\pi m/Ne^2)}$, where e and m are the electronic charge and mass and N is the electron density. Martyn found that in a magnetic field there would be two such natural periods, and that, in the presence of collisional friction, appreciable radiation corresponding to the extraordinary wave of the magneto-ionic theory would escape. He found that the radiation would be likely to come from the borders of moving prominence material.

Shklovsky (1947) also considered that the intense radio noise originated from the oscillations in the "plasma", which was the name given by Langmuir to a current-carrying ionized gas. Langmuir and Tonks (1929) gave both experimental results and a theory to show that a stream of electrons passing through an ionized gas at low pressure sets up radio-frequency oscillations.

More recently, Haeff (1948) has shown both theoretically and experimentally that considerable amplification of radio waves can be achieved over limited wavelength bands when streams of charged particles of different velocities traverse the same region. Haeff considers that streams of charged particles ejected from sunspot regions during solar flares present just the conditions where enormous amplification of space charge fluctuations could occur and thus give rise to intense solar radio noise. Bailey (1948) has also calculated that ionized gases in the presence of electric and magnetic fields can amplify disturbances at certain wave-lengths.

Saha (1946) has considered a possible origin of the radio noise from sunspots in nuclear processes dependent on excitation by magnetic fields. This suggestion is based on results demonstrated by Rabi *et al.* that when atoms are placed in a strong magnetic field which is crossed at right angles by a much smaller rapidly varying field the nuclei, which possess spin, may take up rapidly varying orientations accompanied by radio emissions. Saha also noted that the rotational states of molecules had been shown to be capable of radio-frequency transitions in magnetic fields. He concluded that in sunspots the conditions are appropriate for the emission of metre waves of the right order of intensity, provided a transverse magnetic field across the spot region with the right order of frequency can be postulated. Saha predicted on this theory that sunspots would radiate strongly in the centimetre range. The experimental evidence is, however, that the sunspot radiation is of very much weaker intensity for centimetre waves than for metre waves.

Theories will now be discussed which are based on the view that the kinetic energies of the electrons (and possibly other charged particles) at the source of the intense radio noise must be not less than the values corresponding to the equivalent temperatures as indicated by the radio emission; or in other words, that the radiation intensity is limited by the black-body emission corresponding to the electron temperature at the source. At wave-lengths of a few metres, equivalent temperatures for the Sun's visible disk of the order of 10^{10} deg. K. have been recorded. If the emitting region is of the order of 10^{-3} of the disk, the temperatures for this region must be of the order of 10^{13} deg. K. The equivalent mean kinetic energy of electrons is about 10^9 electron volts. Unsöld (1947) has sought to find evidence of solar charged particles of such energy in certain cosmic ray intensity enhancements at times of solar flares, since, as Forbush (1946) had suggested, sudden marked increases in cosmic ray intensity on 1942 February 28 and March 7, which commenced about 0·3 hour after the onset of a radio fadeout and on 1946 July 25 about one hour after the fadeout onset, might be due to corpuscular streams accelerated to high velocities in transient fields in sunspot regions.

The gyro-magnetic theory of the origin of solar radio noise has been expounded in a different form by Giovanelli (1948), for he assumed that the radiating electrons have far greater energies than the thermal velocities of the normal solar atmosphere. Such an occurrence he derived from his theories of induced currents in the solar atmosphere due to sunspot growth. Current paths make complete circuits which pass below the Sun's surface and maybe partly through the corona. The current is constant across all sections of the circuit; so that with E.M.F.s of 10^8 volts in current circuits, the greater part of the potential drop must be localized in the upper chromosphere and the corona where there is minimum electron concentration. Giovanelli concluded that electrons would reach energies of 10^6–10^7 volts in these regions, and that radiation due to these electrons caused by their spiralling in the magnetic field would occur up to the intensity limit corresponding to their effective black-body temperature (obtained approximately by multiplying the energy in electron volts by 10^4).

Ryle (1948) has also postulated the occurrence of high energy electrons and considered that the sunspot radio noise is thermal radiation corresponding to temperatures of the order of 10^{10} deg. K. Ryle thinks that such temperatures might originate in the following way. Alfvén has shown that the permanent magnetic field of the Sun and the variation of speed of rotation of the solar surface with latitude would cause potential differences of the order of 5×10^8 volts. Ryle stated that if there is a small angle between the magnetic and rotational axes of the Sun there could be a high potential difference between two points on a magnetic line of force, and it is only along the lines of force that currents can flow. He suggested that the potentials developed in this way might be sufficient to maintain normal electron temperatures of the order of 10^6 degrees; and when spots occur, the magnetic lines of force may cut the Sun's surface at points of widely different potential, and hence electron temperatures may attain higher values, of the order of 10^{10} deg. K.

Ryle, however, contended that the radiation could not be due to the free gyration of electrons in the magnetic field, because the magneto-ionic equations do not permit propagation of this radiation outwards into a region of reduced magnetic field. He used the equations for propagation in the same direction as the magnetic

field (see Table III (*b*)). The limiting condition for propagation of the extraordinary wave when the frequency is higher than the gyro-frequency, namely $f(f-f_H)>Ne^2/m$, cannot be fulfilled for $f\approx f_H$. Propagation is always possible, however, into the region where the field is greater, i. e. where $f<f_H$. Thus Ryle argued that gyro-magnetic radiation will take place in a direction towards but not outward from the spot, and he concluded that this action must result in a "gyro-magnetic radiation pressure" which would have an important significance in causing an upward flow of ionized gas in the regions above sunspots.

In order to account for the intense solar radio noise, Ryle considered the regions which correspond to zero refractive index for the ordinary and extraordinary waves, for these are regions of strong absorption and consequently emission will also be strong. In these regions and for a wave parallel to the magnetic field, $f(f\pm f_H)=Ne^2/\pi m$, where the + sign applies to the ordinary wave and the negative to the extraordinary wave. Ryle's theory thus has a similarity to that of Martyn for the quiescent Sun, except that Ryle invoked temperatures of the order of 10^{10} deg. K. above sunspots.

The conditions for the escape of radio waves from sunspot regions have also been discussed at length by Saha (1946, 1947). He used the magneto-ionic equations which apply when the magnetic field and the wave direction are not coincident. Assuming that the radio noise originates in lower spot regions where $f<f_H$, he concluded that the extraordinary wave satisfying the condition that $f(f+f_H)>Ne^2/m$ can be propagated (compare Table III (*a*)). He considered that this extraordinary wave could escape, because he accepts that the above limiting condition also holds even beyond gyro-magnetic resonance region. In other words, Saha considered extraordinary waves corresponding to both $f(f\pm f_H)>Ne^2/\pi m$ when $f<f_H$, although the positive sign has not generally been accepted as permissible when $f<f_H$.

It is thus apparent that there is much diversity of opinion about the origin of the intense solar radio noise disturbances and there appears much scope for the clarification of ideas, both with regard to the necessity for assuming the existence of true temperatures equal to or greater than the observed enormously high equivalent temperatures, and also with regard to the application of magneto-ionic theory to disturbed regions of the solar atmosphere. In order to eliminate speculation, however, more observational data are needed, and long-term analyses of the characteristics of radio noise emissions over a wide range of wave-lengths and the relation to other solar data would be most valuable.

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THE EARTH'S UPPER ATMOSPHERE

D. R. Bates

1. *Introduction.*—Our knowledge concerning the Earth's upper atmosphere has increased rapidly in recent years, following on the great general advance in physics and technology. Interest has been stimulated by the unexpected nature of some of the discoveries made, and specialists in many branches of science have been attracted by the widely diverse problems that arise in the study of the noctilucent clouds, the ionized layers, the tidal motions and their magnetic effects, the radiations emitted by the night sky and by other sources, the photochemical and ionic reactions occurring, the degree of diffusive equilibrium established, the rate of escape of constituent gases into interplanetary space, etc. The investigations being carried out are of particular importance to the astronomer in that they yield information on that part of the solar spectrum that cannot be observed directly from ground level.

A difficulty in giving a systematic account of the subject is that the various aspects of it are so closely linked together that it is not possible to discuss one without making use of evidence provided by others. In the present article the procedure adopted will be first to summarize what is known about the constitution, the density and the temperature at various levels. The section on the basic properties will contain references to phenomena such as the aurorae, which will be considered more fully in later sections.

2. *The basic properties*

2.1.—Many methods have been developed for the exploration of the upper atmosphere. They may be classified into the following main groups:—

(A) methods depending on the use of controlled probes either (i) of a material nature (i.e. instruments borne by balloons or rockets) or (ii) of a wave nature (e.g. sound or radio pulses),

and (B) methods depending on the study of naturally occurring events (such as the passage of meteors through the atmosphere).

Each group has its merits and defects. Material probes provide us with the most direct data but their range is not very great. Thus the decrease in the buoyancy of the air restricts balloon ascents to altitudes up to only about 35 km. and while the rockets now used can rise to well above 100 km. it is by no means easy to ensure that the instruments they carry record reliably at the higher levels. As would be expected, wave probes have in general a much more extensive range. They have also the advantage that with suitable apparatus they can be used continuously. Unfortunately the types of measurements that can be made by means of them are rather limited. Radio pulses, for instance, give directly only data on the amount of ionization. It is true that deductions can be made regarding the main atmosphere, but these are subject to some uncertainty. The remaining method, the study of naturally occurring events, has great promise, especially as such events are not restricted to any narrow region—auroral displays alone should eventually yield information on the constitution, density and temperature of a region extending from rather below the 70-km. level to rather above the 1000-km. level. However,

much of the observational work that has been done up to the present is insufficiently quantitative; furthermore, in some cases there is as yet no secure theoretical basis for the interpretation of the measurements made.

We will now consider the actual results that have been obtained. Attention will be confined to averaged conditions and no attempt will be made to discuss the little that is known concerning the seasonal and latitudinal effects.

The composition of the air at ground level can be determined chemically. Table I (which is based on the work of F. A. Paneth (1)) shows the fractional volume concentrations of the main constituents other than water vapour. By virtue of Avogadro's Law these fractional volume concentrations give directly the relative numbers of the different molecules and atoms present. As can be seen, it is a good approximation to regard the air as being a mixture of nitrogen and oxygen molecules only, with the former four times more numerous than the latter.

TABLE I

Composition of dry air

Constituent	Fractional volume concentration
Nitrogen (N_2)	0·7808 } 0·9903
Oxygen (O_2)	0·2095 }
Argon (A)	0·0093
Carbon dioxide (CO_2)	0·0003
Neon (Ne)	2×10^{-5}
Helium (He)	5×10^{-6}
Krypton (Kr)	1×10^{-6}
Hydrogen (H_2)	5×10^{-7}

Before discussing the experimental work on the atmosphere at higher levels some elementary theoretical concepts must be recalled. Under idealized equilibrium conditions the altitude distribution of each constituent is independent of the presence of the other constituents and is governed by the well-known hydrostatic equation

$$\frac{d\{\log(\rho T)\}}{dz} = -\frac{mg}{kT}, \tag{1}$$

ρ being the density of the particular constituent, T the temperature, z the altitude, m the molecular mass (again of the particular constituent), g the acceleration of gravity and k Boltzmann's constant. It is customary to define kT/mg (which is of the dimensions of length) as the local scale height and to denote it by the symbol H. We thus have simply,

$$\frac{d\{\log(\rho T)\}}{dz} = -\frac{1}{H}. \tag{2}$$

The great importance of this equation is that it provides a relationship between the density distribution and the temperature distribution, so that if either is determined experimentally the other can be deduced. In general, the necessary integration has to be carried out by numerical methods, but in the special case of an isothermal atmosphere it can be done analytically and the density distribution can be written in the form

$$\rho = \rho_0 \exp(-z/H). \tag{3}$$

The most convenient form in which to express the density is as the particle concentration (that is, as the number of molecules or atoms in unit volume). At ground level the total particle concentration of the air is about $2{\cdot}6 \times 10^{19}/\text{cm.}^3$.

In the preceding paragraph we have discussed the equilibrium distribution of a complex gas. We must now consider how far this equilibrium can be attained. Suppose that at one stage there is uniform mixing, so that the constitution is the same at all levels. Owing to diffusion the component gases tend to separate out and take up the distribution dictated by their different molecular masses: gases of high molecular mass tend to concentrate more near ground level than gases of low molecular mass (*cf.* (1), (2) or (3)). The time required for such a separation process to become important has been investigated by H. B. Maris, P. S. Epstein, S. K. Mitra and H. Rakshit (**2**). It is found that diffusion is extremely slow except at great altitudes. Now observations on the motions of meteor trails and of noctilucent clouds show that rapid and turbulent winds are prevalent in the upper atmosphere. The mixing action of these opposes diffusive separation, and there can be little doubt completely prohibits it at least below the 100-km. level, as for this region calculations show that the time required for equilibrium to be reached is actually more than a year. No direct experimental confirmation of the predicted essential constancy in the composition of the air throughout the region just mentioned is yet available, but it can at least be said that the most recent analyses of samples obtained in balloon flights up to between 25 and 30 km. show no indication of any appreciable increase in the proportion of the lighter gases. It must be emphasized that 100 km. is only a *lower limit* to the altitude at which diffusive separation first becomes important. Calculation of the *actual* altitude is unfortunately not possible at present owing to lack of precise information on factors such as the efficiency of the mixing effects; but it seems not unlikely that it is between 200 and 300 km. For simplicity many authors neglect diffusive separation altogether. In this case the hydrostatic equations already quoted can continue to be used provided only m is replaced by $\overline{m}$ the weighted mean molecular mass of the various constituents. As previously stressed, the relationship between the particle concentration and temperature distribution permits us to be contented by experimental information on either.

We are now in a position to examine the atmospheric measurements themselves. Many of the sources of information we will discuss were first considered together systematically by D. F. Martyn and O. O. Pulley (**3**).

As long ago as in 1892 investigations using balloon-borne instruments were begun by G. Hermite and G. Besançon. At quite an early stage it was found that the lower atmosphere could conveniently be divided into two regions. In one, the troposphere, the temperature decreases with increasing altitude, and in the other, the stratosphere, the temperature is independent of altitude. The extent and temperature of these regions depend both on the season and on the latitude. However, Table II gives sufficiently representative figures for the present purpose.

TABLE II

The lower atmosphere

Region	Extent	Temperature
Troposphere	0–10 km.	Decreases from 285 deg. K. at base to 220 deg. K. at top
Stratosphere	10–20 km.	220 deg. K. throughout

Unless there is some theoretical basis for it the extrapolation of experimental results is a speculative process; but it is one that is often instructive. At this stage it is natural therefore to consider whether there is any possibility that the simple conditions observed in the stratosphere can continue to great altitudes. Using the data in Tables I and II we can integrate equation (2) through the region of the troposphere to obtain the particle concentration at the 10-km. level. If we assume that above this the temperature remains at 220 deg. K. and that the constitution remains the same as at ground level (so that the mean molecular mass is about 29) it follows that the scale height also remains constant and has the value 6·5 km. If this is accepted, the simple exponential formula (3) can be used to predict the particle concentration throughout the upper atmosphere. The results obtained by such a procedure are utterly unacceptable. For example, the predicted particle concentration at an altitude of 300 km. is rather less than 1/cm.^{3}. Radio workers, however, find that the electron concentration in the F_2 layer (which is located at about the 300-km. level) is as high as 10^6/cm.^{3}: and there can be no doubt that the molecule concentration must be even greater. It is clear therefore that the assumptions we made in carrying out our extrapolation must be incorrect. In particular, since we predicted too rapid diminution of the particle concentration, the value of H we adopted must be too small. Remembering that this quantity is equal to $kT/\overline{m}g$ we see that above the stratosphere,

either (i) $\overline{m}$, the mean molecular mass, must decrease owing to an increase in the proportion of light gases such as hydrogen and helium,

or (ii) T, the temperature, must become greater.

The first possibility is now generally regarded as unlikely, it being contended that if hydrogen and helium were important constituents their characteristic emissions would appear more prominently than they do in the spectra of the upper atmospheric sources of luminosity. This argument is plausible, but it must be examined in detail before it is accepted. Actually, nothing can be deduced from the fact that the night-sky light seems to contain no contribution from either of the two elements concerned: for not only does it mainly originate from rather low in the atmosphere (perhaps from near the 100-km. level), but in addition the excitation mechanisms operative, besides being insufficiently energetic, are highly selective; the D doublet, for example, is one of the most prominent features of the spectrum in spite of only a minute trace of sodium being present. Aurorae, however, provide evidence that is at least very suggestive. The collision processes involved are different from those responsible for the major part of the night-sky light and are of such a nature that it would be expected that they would excite all atmospheric constituents with approximately equal facility. If this expectation is correct (*cf.* Section 4) it is not easy to dismiss the simple direct interpretation of the well-established result that the spectra of all aurorae (including those stretching to altitudes as high as 1100 km.) are dominated by nitrogen and oxygen emissions and only show hydrogen and helium emissions weakly: but the question cannot be regarded as finally closed until a proper quantitative theory of auroral processes is available. The evidence given by twilight observations remains to be considered. If hydrogen occurs in the upper atmosphere the hydrides *NH* and *OH* would be formed as a result of photochemical action. These substances resonate strongly in sunlight, emitting bands near λ3360 and λ3090 respectively. This property provides a very sensi-

tive means of detecting their presence in any illuminated gas; through it, for example, P. Swings, C. T. Elvey and H. W. Babcock (**4**) were able to establish that both hydrides occur in comets. Now, neither $\lambda 3360$ nor $\lambda 3090$ have been reported as being emitted from the twilit atmosphere. Even allowing for the fact that the spectral region concerned is difficult to study, it seems reasonable to suppose that the hydrides are rare or absent and in consequence it is likely that hydrogen itself is not a major constituent (at least at moderate altitudes).

Since the combined evidence from the auroral and twilight emissions does not favour the hypothesis that the upper atmosphere is composed mainly of the light gases, we turn to the alternative possibility mentioned. That the temperature should increase greatly above the stratosphere might at first appear intrinsically improbable. But, in fact, the experimental evidence for such an increase is now conclusive and, further, the reason for it is understood. Measurements made during balloon ascents provide the most direct support. The early work, to which reference has already been made, gave no information on the atmosphere above about the 20-km. level. Improvements in equipment and technique gradually enabled higher and higher altitudes to be reached. In 1930, A. Wigand (**5**) succeeded in sending a balloon to the 33-km. level. He found that *between* 20 *and* 33 *km. the temperature increases by a few degrees.* This important discovery has been fully confirmed by other workers.

A remarkable effect is associated with the propagation of sound through the Earth's atmosphere. The audibility of a source does not fall off steadily with increasing distance; instead, after an initial fall-off, it rises and passes through a maximum at a distance of 200 or 300 km. from the source. This anomalous maximum is relatively weak and it can only be detected when the sound generated is very intense, as is the case in explosions. Proof of its occurrence does not, however, require the use of special instruments: there are, for example, many recorded instances of the sound of the cannon fire in a battle being heard distinctly by people a long way off but not being heard at all by people comparatively close to the fighting. The cause of the phenomenon is simple. For a given gas the velocity of sound is proportional to the square root of the absolute temperature and is independent of the density. Bearing these facts in mind, consider the consequences of an increase in the temperature above the stratosphere. An outwardly progressing sound wave will tend to be refracted downwards; and, if the temperature increase is sufficient, it will be deviated to such an extent that it will return to ground level and give rise to the peculiar secondary zone of audibility that is observed. The whole process is closely analogous to that involved in the formation of an optical mirage. Detailed study of the anomalously propagated wave provides invaluable information on upper atmospheric conditions. By an analysis of a series of measurements on angles of descent and times of flight F. J. W. Whipple, P. Duckert and B. Gutenberg (**6**) independently concluded that the *temperature rises considerably in the region above the* 20*-km. level and actually reaches a value as great as* 350 *deg. K. at an altitude of some* 50 *km.* This pioneer work requires to be refined to include proper allowance for the effect of winds.

Controlled acoustic probes can only be used up to altitudes of a little over 50 km. But fortunately Nature provides a sound source high in the atmosphere in the form of detonating meteors. F. J. W. Whipple (**7**) noticed that detonations occurring above 60 km. are rarely audible. He suggested that the reason is that

at this level the temperature begins to decrease again so that down-coming sound waves are refracted back.

More quantitative information on conditions in the upper atmosphere between the 40 and 120-km. levels can be obtained from visual and photographic study of ordinary meteors. A vast amount of observational data has been collected by such workers as W. F. Denning and E. Öpik (**8**); the theoretical investigations of F. A. Lindemann, G. M. B. Dobson, C. M. Sparrow, P. S. Epstein, N. Herlofson and others (**9**) have led finally to an understanding of the factors controlling the heating, evaporation, luminosity and retardation of a meteor passing through the atmosphere. F. L. Whipple (**10**) has recently published a comprehensive survey of the whole subject. In this he considered, in particular, four separate parameters—the deceleration, and the altitudes of the beginning and end of the track and of the point of maximum light emission. By using the measurements available on these in some formulae he developed, he was able to deduce the probable density distribution (and hence also the probable temperature distribution) in the atmosphere. His results (combined with those obtained from the balloon and anomalous propagation of sound investigations) are summarized in Table III.

TABLE III

Temperatures and particle concentrations below the 120-km. level

Altitude (km.)	Temperature (deg. K.)	Particle concentration ($/cm.^3$)
0	285	$2{\cdot}6 \times 10^{19}$
10	220	9×10^{18}
20	220	2×10^{18}
40	250	7×10^{16}
60	350	8×10^{15}
80	200	1×10^{15}
100	260	7×10^{13}
120	350	6×10^{12}

As can be seen they confirm the fall in temperature above the 60-km. level indicated qualitatively by the observations on detonating meteors. It will be noticed too that the fall is very rapid and ends at about 80 km., beyond which altitude the temperature again rises. We should perhaps here emphasize that while the reality of the main trends exhibited in the table is not in serious doubt, the accuracy of individual figures is very uncertain.

The main methods used in exploring the region between 0 and 120 km. have now been described. There are, however, a number of supplementary sources of information which can be used to check the correctness of the deductions made.

(i) In principle it is possible to estimate the density distribution up to perhaps 60 km. by studying the extent to which the air particles produce scattering in a searchlight beam or in the radiation from the setting or rising Sun. Attempts to do so have been made by W. Linké, E. O. Hulburt, I. A. Khvostikov and others (**11**). The necessary measurements are difficult to perform and the results obtained by the different workers are rather contradictory: but at least some support is given to the conclusions already reached on the conditions in the lower atmosphere and above the stratosphere.

(ii) It is known from laboratory experiments that the definition of ozone absorption bands depends on the temperature. Now ozone is present in the

Earth's atmosphere and its absorption bands appear in the solar spectrum (*v. infra*). From an analysis of measurements made on them R. Penndorf (**12**) has estimated that in the neighbourhood of the 50-km. level (where a considerable part of the absorption occurs) the temperature is about 320 deg. K.

(iii) O. Jesse and C. Störmer (**13**) have found that the noctilucent clouds are restricted to a narrow altitude range centred at 82 km. Two explanations of this have been advanced; both demand that at the 82-km. level there should be a temperature minimum (which is in accord with the data in Table III). W. J. Humphreys (**14**) claims that the clouds are formed of ice crystals. If this view is correct the temperature must be as low as 160 deg. K. An alternative possibility is that the particles involved are volcanic dust. To prevent such dust being carried to greater heights by convective currents the atmosphere in the region near the 82-km. level must, as E. Regener (**15**) has pointed out, be stable, which implies that the temperature must begin to rise.

(iv) By using radio probes it is possible to make certain measurements on the properties of the ionized layers from which the scale heights and hence the temperatures, in the regions concerned, can be estimated (*cf.* Section 3). K. G. Budden, J. A. Ratcliffe and M. V. Wilkes (**16**) have found that toward the base of the D layer, at 70 km., the scale height is 6 km.; E. V. Appleton (**17**) has found that in the E layer, at 120 km., it is 11 km. The corresponding temperatures are approximately 200 deg. K. and 400 deg. K. respectively. These figures are in fair agreement with those given in Table III but too much significance should not be placed on this as the interpretation of radio measurements involves somewhat doubtful simplifying assumptions. It is also possible to measure the frequency with which the electrons collide with the neutral particles. Ideally, this should enable the gas density to be calculated, but at present the method is scarcely quantitative.

(v) The temperature of a gas controls the distribution of the molecules amongst their rotational energy levels in accordance with Boltzmann's Law. Consequently it characterizes, and can be determined from, the spectrum emitted. L. Vegard and E. Tönsberg (**18**) have made careful measurements on the profiles of the most intense auroral bands (which originate actually from N_2^+ ions). From these they were able to deduce that at an altitude of 120 km. the temperature is about 320 deg. K. The principles employed appear simple and the result just quoted agrees quite well with the data of Table III. However, a series of measurements that will be discussed later suggests that complete reliance cannot yet be placed upon this method.

(vi) Tides occur in the atmosphere, as in the oceans, and give rise to periodic variations in the barometric pressure. The solar semi-diurnal variation is abnormally large. Lord Kelvin (**19**) pointed out that this could be explained by ordinary resonance amplification if the atmosphere has a mode of oscillation of period closely equal to 12 hours. Evidence for the existence of a different mode, with a period of only about $10\frac{1}{2}$ hours, has been provided by G. I. Taylor (**20**) from the analysis of the speed of propagation of the explosive waves from the Krakatoa eruption of 1883 and from the great Siberian meteor of 1908. Now it is possible to compute the modes of oscillation of an atmosphere of given properties. Hence an overall check can be applied to any proposed model by determining whether or not it has the two modes demanded by observation. Calculations by C. L. Pekeris and by K. Weeks and M. V. Wilkes (**21**) indicate that a structure of the

type given in Table III is satisfactory: indeed, they go further, they show that certain of the features (in particular the great temperature maximum near 60 km.) are *necessary* characteristics.

Thus far we have omitted reference to the information derived from the investigations, with rocket-borne instruments, that are at present being carried out in New Mexico by the staff of the United States Naval Research Laboratory (**22**). We have done this deliberately, as we felt it desirable to give first an account of the ways in which human ingenuity has overcome the inherent difficulty of determining the properties of the inaccessible region of the atmosphere. Now, when we do at last turn to the rocket measurements, we find in fact that little need be said about them: for (and this is a remarkable tribute to the combined efforts of the various workers we have mentioned) they are in essential agreement with the general conclusions already reached—they confirm for example that the temperature, after falling in the troposphere and remaining constant through the stratosphere, rises to a considerable maximum at about 60 km., then falls to a low minimum at about 80 km. and finally begins to increase again. The investigations are still, of course, at a preliminary stage. There can be little doubt that in the near future they will provide more precise information than do the older methods.

2.2.—Before continuing any further our survey of the density and temperature distributions it is desirable for us to discuss some changes that occur in the constitution.

As astronomers have long been aware, the Earth's atmosphere is opaque to radiation of wave-length less than about 2900 A. By the identification of a group of absorption bands appearing in the solar spectrum near the transparency limit, W. N. Hartley in 1880 established that the opaqueness is caused by the occurrence of ozone in the atmosphere. Later workers, notably C. Fabry, H. Buisson, E. and V. H. Regener, G. M. B. Dobson and F. W. P. Götz (**23**), have succeeded in deriving quantitative information on this interesting constituent from measurements on the absorption bands at various zenith angles of the Sun, and at various heights above the ground. They find that it forms a diffuse layer. The maximum of this lies near the 25-km. level. Even here the concentration of ozone molecules is only some 3×10^{12}/cm.^{3}, which is about 4×10^{-6} of that of the other constituents.

S. Chapman, R. Mecke, O. R. Wulf and L. S. Deming (**24**) have investigated the origin of the ozone layer. It appears that the primary process is the photo-dissociation of molecular oxygen,

$$O_2 + h\nu \rightarrow 2O. \tag{4}$$

An oxygen atom liberated may collide with an oxygen molecule and may unite with it to form ozone, provided some third particle (an atom or molecule of any of the constituents) is available to take up the excess energy and momentum; thus if X represents the third particle,

$$O + O_2 + X \rightarrow O_3 + X. \tag{5}$$

A number of opposing processes also occur. In particular the ozone may suffer photo-dissociation,

$$O_3 + h\nu \rightarrow O_2 + O, \tag{6}$$

or it may react with free oxygen atoms to reform oxygen molecules,

$$O_3 + O \rightarrow 2O_2. \tag{7}$$

Numerical calculations show that these four processes lead to an equilibrium distribution similar to that observed. Even without detailed analysis it can be seen in general terms that the ozone will be confined to a layer instead of being spread throughout the whole atmosphere. The essential argument is that the ratio of the efficiency of the formation processes to that of the destructive processes diminishes rapidly both at very great altitudes and at very low altitudes; at these extremes the equilibrium concentration must therefore tend towards zero, and at some intermediate altitude it must pass through a maximum.

In spite of being a rare constituent, the ozone exercises a profound influence on upper atmospheric conditions. E. H. Gowan and R. Penndorf (**25**) have shown that the energy it absorbs from the solar radiation is responsible for the temperature increase above the stratosphere. This might at first appear peculiar, since the maximum concentration of the ozone occurs at about the 25-km. level, whereas the temperature continues rising up to almost the 60-km. level. There is however no discrepancy. The explanation is simply that the ozone is so opaque that a great part of the energy is absorbed very high in the layer. G. H. Godfrey and W. L. Price (**26**) have investigated the second temperature increase setting in at an altitude of 80 km. They were able to show that it is due to absorption caused by the main constituents.

As would be expected, ozone is not the only minor compound formed in the upper atmosphere. Others, such as nitrous oxide, have also been reported. The problems raised are of rather limited general interest and we will not discuss them here. Instead we will proceed to consider the presence in the upper atmosphere of certain foreign elements.

The *D* doublet of sodium $\lambda 5894$ appears in the spectrum of the night sky as has already been mentioned. It was first identified by R. Bernard, J. Cabannes, J. Dufay and G. Gauzit (**27**). During twilight it is observed to be greatly enhanced. There is little doubt that this is caused by *resonance scattering* by free sodium atoms in the illuminated region of the atmosphere :

$$\begin{cases} Na + h\nu \rightarrow Na', \\ Na' \rightarrow Na + h\nu, \end{cases} \tag{8}$$

the prime signifying an excited atom. Extensive measurements have been made on the intensity of the twilight enhancement. By analysing these and utilizing the detailed knowledge that is available on the absorption and re-emission processes (8) it is possible to show that at an altitude of 70 km. the concentration of sodium atoms is 10^3 to 10^4/cm.^{3}, and that above this it decreases at much the same rate as does the concentration of the other gases (**28**). From the data in Table III it can hence be seen that *sodium atoms form approximately* 10^{-12} *of the total atmosphere in the region concerned.* This extreme rarity is emphasized, as undue wonder is sometimes expressed at such a constituent being present. What is remarkable rather is that it is detectable. We should perhaps mention in parenthesis that theoretical considerations indicate that the action of solar radiation may produce a high degree of ionization of the sodium. At some levels the positive ions may be considerably more numerous than the neutral atoms (**29**). The concentrations normally given refer to the latter only and do not include the former.

Several workers have speculated on the origin of the sodium. Volcanic and meteoric dust are two plausible sources that have been suggested by S. Chapman (**30**). As far as can be judged, either possibility may be adequate.

quantitatively. Even granted, however, an ample supply it still remains to explain why such an active element exists in the free atomic state instead of becoming oxidized. This presents no real difficulty: indeed, to some extent the problem only appears acute because intuitive feeling is a misleading guide to the chemistry of a gas of very low density. Consider how oxidation can occur. There are two energetically allowable collision processes,

$$Na + O + X \rightarrow NaO + X \tag{9}$$

and

$$Na + O_3 \rightarrow NaO + O_2. \tag{10}$$

Both are infrequent; the first because it requires (as is indicated) some third particle to be available in the immediate neighbourhood, and the second because it involves ozone, which is a very rare constituent. Crude theoretical estimates actually indicate that it is quite possible that days elapse before any particular sodium atom becomes oxidized. S. Chapman (**30**) has pointed out that the sodium oxide eventually formed may be reduced by the action

$$NaO + O \rightarrow Na + O_2. \tag{11}$$

Upper atmospheric conditions are more favourable to (11) than to (9) or (10), since it requires merely a simple encounter between two particles, and since it involves atomic oxygen which (as will be seen shortly) is an important constituent. The occurrence of free sodium atoms is therefore in no way anomalous.

Other foreign elements have not been detected, but as spectral emission depends on very many factors it cannot be concluded that they are absent—this indeed would seem unlikely in view of the sources postulated for the sodium. It is perhaps not unreasonable to assume that they are present in some form in amounts approximately proportional to their cosmic abundances. On this hypothesis the *total* particle concentration, arising from the various metals, would be of order 10^5/cm.^{3} at the 70-km. level. Such an estimate is of course highly tentative.

As has already been mentioned, the oxygen in the upper atmosphere is subject to photo-dissociation,

$$O_2 + h\nu \rightarrow 2O. \tag{12}$$

It may however be reformed from the oxygen atoms as a result of the three-body collision process

$$2O + X \rightarrow O_2 + X. \tag{13}$$

The general features of the equilibrium that ensues can be deduced by a simple and direct argument due to S. Chapman (**31**). Consider the rates at which the two processes concerned occur. Clearly that of (12) is equal to some constant K_1 times the product of I, the intensity of the radiation causing the dissociation, and $[O_2]$, the concentration of the molecular oxygen; that of (13) is equal to some other constant K_2 times the product of $[O]^2$, the square of the concentration of the atomic oxygen, and $[X]$ the concentration of the necessary third particles. In the steady states these rates must balance thus:—

$$K_1 I[O_2] = K_2[O]^2[X]. \tag{14}$$

It is convenient to rearrange this equation in the form

$$[O]/[O_2] = \{K_1 I/K_2[O_2][X]\}^{\frac{1}{2}}. \tag{15}$$

At low levels the oxygen is of course entirely molecular, $K_1 I$ being many orders smaller than $K_2\,[O_2][X]$ on account of the extreme attenuation of the solar radiation. Progressing upwards, however, I increases and eventually reaches its incident value: in addition both $[O_2]$ and $[X]$ decrease steadily. Hence from (15) it is apparent that the ratio $[O]/[O_2]$ rises and ultimately becomes very great. *At high levels therefore the oxygen is essentially completely dissociated.* This conclusion is consistent with the spectroscopic observations, which show that atomic oxygen gives a major contribution to the emission from the night sky and from aurorae.

Detailed numerical calculations on the equilibrium have been carried out by O. R. Wulf and L. S. Deming, by R. C. Majumdar, and by H. Rakshit (**32**). Though the treatments differ considerably (particularly in the assumptions on the recombination process), very similar results are obtained. These indicate that the transition from the molecular region to the atomic region occurs within a narrow altitude range near the 100-km. level.

Unlike oxygen, nitrogen is extremely difficult to dissociate. It is so stable, indeed, that a few years ago most authors considered that it would remain in the molecular form up to very great altitudes. This belief was strengthened by the knowledge that bands of the molecule appear prominently in the spectra of all aurorae, irrespective of their altitude. Recently, however, doubts have arisen. Certain evidence (discussion of which is best deferred until later) indicates that atomic nitrogen is far from rare, even at comparatively low levels: according to one estimate (*cf.* Section 5) its concentration near the 100-km. level is at least 4×10^{11}/cm.^{3}. If this is correct, and if photo-action is directly responsible, then a difficulty at once presents itself. An equilibrium formula, similar to (15) but generalized to allow for various recombination processes, can readily be derived. Unless the atmosphere is so turbulent that mixing is very effective, the ratio $[N]/[N_2]$ would increase rapidly with altitude. Hence the acceptance of a *moderate* value of it at the 100-km. level would seem to demand the acceptance of a *large* value of it at the 1000-km. level. The high degree of dissociation suggested by this reasoning would not have been predicted from the auroral observations mentioned. No such apparent discrepancy would occur if the suspected permanent nitrogen atom content of the atmosphere could be attributed to collisions, since of course these are infrequent at great altitudes. The possibilities are however severely restricted by energy considerations: thus a reaction like

$$O + N_2 \rightarrow NO + N \qquad (16)$$

cannot proceed unless one of the initial particles is in an excited state. It may, in fact, be that dissociating collisions are unimportant. Certainly no satisfactory theory involving them has yet been developed.

In view of the several obscurities to which attention has been drawn, it is clear that the form of the upper atmospheric nitrogen is still problematical. A final decision on the matter will probably only be reached when a deepened understanding of various excitation mechanisms enables the inferences that can be drawn from the observed spectral emissions to be fully appreciated.

2.3.—We will now return to the discussion of the density and temperature distributions, bearing in mind, of course, that the dissociation occurring leads to a reduction in the mean molecular mass and hence to an increase in the local scale height.

As we seek to extend our exploration higher and higher the difficulties encountered naturally increase. In consequence, it is not surprising that we have but scanty information on the properties of the vast region above the 120-km. level, still to be surveyed. The rather miscellaneous evidence available comes from a number of sources which can conveniently be considered in groups.

(i) It has already been noted that a lower limit to the particle concentration at 300 km. is 10^6/cm.^{3}, the electron concentration in the F_2 layer. This figure is in fact a gross lower limit. Thus general theoretical consideration of the factors governing the formation of the layer indicate that in the region of the maximum (that is near 300 km.) the particle concentration is at least 10^9/cm.^{3} and is probably higher. Again, V. C. A. Ferraro (**33**) has shown that diffusion away of the free charges would be so rapid as to destroy the characteristics of the layer unless the particle concentration is of the order 10^{10}/cm.^{3}, which is only about 600 times smaller than the value at an altitude of 120 km. (*cf.* Table III). From formula (3) it is hence apparent that the mean scale height in the region between the 120 and 300-km. levels must be large. Some confirmation of this is provided by the measurements made by radio workers on the thickness and other detailed properties of the F_1 and F_2 layers. These may be interpreted as indicating that at altitudes of approximately 220 and 300 km. the scale heights are about 30 and 70 km. respectively (**34**). Unfortunately but little accuracy can be claimed, since the method used in reducing the observational results involves some rather dubious assumptions. Nevertheless, the figures quoted are in very good agreement with estimates made by L. Harang (**35**) from the intensity distribution along auroral rays. In deducing temperatures from the scale heights it is probably best to adopt a mean molecular mass corresponding to complete dissociation of the oxygen and only slight dissociation of the nitrogen (except perhaps at extreme altitudes).

TABLE IV

The properties of the atmosphere in the region of the F_1 and F_2 layers

Layer (and altitude)	Particle concentration	Temperature
F_1 (220 km.)	1×10^{11}/cm.^{3}	1000 deg. K.
F_2 (300 km.)	2×10^{10}/cm.^{3}	2000 deg. K.

From information of the type summarized above, Table IV was drawn up some years ago by H. S. W. Massey and the writer (**36**) to provide a provisional model of the atmosphere in the region of the F_1 and F_2 layers. Perhaps the particle concentrations and temperatures given might now be regarded as slightly high but there is insufficient evidence to justify a revision of them at present.

(ii) The red line of atomic oxygen λ6300 is, like the *D* doublet of sodium, enhanced during twilight. C. T. Elvey and A. Farnsworth (**37**), amongst others, have studied the phenomena in some detail. They find that the morning enhancement may actually be detectable when the Sun is only illuminating the atmosphere above the 1300-km. level. Their measurements may provide valuable evidence on the distribution of the oxygen at very great altitudes. Those in the lower half of the total investigated range (which presumably are the most reliable) have been analysed on the assumption that resonance scattering (as (8)) is the responsible mechanism (**38**). The results obtained are remarkable. It seems that the scale height tends to increase upwards, *reaching a value corresponding to a temperature of* 4000 *deg. K. or even considerably more between the* 500 *and* 700*-km. levels*:

and in this region the particle concentration is still apparently somewhat greater than $10^9/cm.^3$. As need scarcely be stressed, these estimates must be treated with the greatest reserve: it is not unlikely that the phenomena are more complicated than has been supposed.

Aurorae provide some evidence in support of the view that the temperature is high. The fact that they have been observed at an altitude of 1100 km., on some occasions (when the atmosphere is sunlit), indicates that the particle concentration is still appreciable here. In particular, as N_2^+ bands appear strongly it seems scarcely likely that nitrogen molecules are rarer than 10^2/cm.^{3}. This means that 5×10^{-9} is a lower limit to the factor by which their concentration diminishes between the 300 and 1100-km. levels. It follows at once that the N_2 mean scale height is at least about 40 km. and hence (even if part of the diminution does not arise from increasing dissociation) *the temperature is at least about* 1500 *deg. K.* We feel we have been cautious in taking the concentration of nitrogen molecules to be 10^2/cm.^{3} at 1100 km.; but even if the true value is several orders smaller, a temperature as high as 1000 deg. K. is still required for consistency.

(iii) At sufficiently great altitudes the gas density becomes so low that the average distance travelled by an atom or molecule before experiencing a collision is comparable with, or greater than, the local scale height: this mean free path depends also on the direction, particles moving upwards colliding at less frequent intervals than particles moving downwards. The term *exosphere* is usually applied to the general region where such conditions prevail, or more precisely to the region above the critical level where the horizontal mean free path is equal to the scale height. From collision cross-section data it can be shown that if the scale height is 100 km. (which is the probable value) the particle concentration at the critical level is about 4×10^7/cm.^{3}. This concentration is likely to be reached below an altitude of 1000 km.

The exosphere has been extensively investigated by J. H. Jeans, E. A. Milne, J. E. Jones, E. O. Hulburt, S. K. Mitra, A. K. Banerjee and L. Spitzer (**39**). Its properties are remarkably simple. The various constituents are throughout in complete diffusive equilibrium, the altitude distribution of each following the standard isothermal formula (*cf.* Section 2.1) with the exponential coefficient corresponding to the temperature at the critical level. Now this temperature controls the rate of escape of the atmospheric gases into interplanetary space. The fact that nitrogen and oxygen are clearly not being lost to any appreciable extent requires that it be less than 6000 deg. K. More useful information is provided by the consideration of the position regarding helium. This element must be escaping, since the number of helium atoms present in a column of the atmosphere of cross-section 1 cm.^{2} is found by F. A. Paneth (**40**) to be about 5×10^{20}, whereas, according to an estimate by F. A. Lindemann (**41**), the corresponding number discharged into the atmosphere in geological time by radioactive rocks is about 6×10^{21}. The problem presented was first discussed in detail by J. H. Jeans. Recently it has been taken up again by L. Spitzer (**42**), who, after modifying the earlier treatment, concluded that the temperature at the critical level is probably about 1500 deg. K. He also showed that the thermal conductivity of the atmosphere is such that it is likely that the temperature remains essentially constant from the exosphere down to an altitude of perhaps 200 km. or even rather lower.

(iv) All the evidence so far presented indicates that the temperature of the atmosphere in the region under discussion is high. Further, L. Spitzer (**42**) has demonstrated that a high temperature is theoretically plausible, considerable energy being absorbed from the solar radiation and the dissipation processes being relatively inefficient. The whole picture therefore appears consistent. Unfortunately, however, it is seemingly quite incompatible with some direct measurements that must now be described.

It has already been noted (Section 2.1) that L. Vegard and E. Tönsberg have determined the temperature of the atmosphere near the 120-km. level by the study of the rotational structure of the N_2^+ bands emitted by aurorae. Using the same method they later sought to obtain information on conditions at greater altitudes. *Measurements they made indicate that even towards the summit of auroral streamers, at perhaps* 200 *km., the temperature is not greater than* 340 *deg. K.* The serious nature of the conflict with the results given earlier is best revealed by considering the density distribution. Thus an elementary calculation shows that the scale height associated with a temperature of 340 deg. K. is so low that the particle concentration in the F_1 layer would be only a little over 10^8/cm.^{3}: but as we have seen, there is reason to suppose that the particle concentration in the F_2 layer (almost 100 km. higher) is about 3×10^{10}/cm.^{3} (*cf.* Table IV).

Some workers have argued that the atmosphere is not in true thermal equilibrium and that in consequence little significance should be attached to the temperature associated with the distribution of the molecular constituents amongst their rotational levels, as this may be very different from the temperature associated with the translation motion (which is what determines the scale height). It is unwise to dismiss the matter so lightly. Ordinary collisions are very effective in causing transfer of rotational and translation energy and there can be no doubt that they are sufficient to maintain fully the general equilibrium at the altitudes concerned. The excited N_2^+ ions from which the bands originate are admittedly in a special category: they result from *abnormal* collisions and their radiative lifetime is so short that if the equilibrium was disturbed by these it could not be restored before the emission occurred. Impacts, either by fast electrons or by fast protons (or other heavy particles), must be the cause of the excitation. But laboratory measurements show that the former do not appreciably affect the rotational temperature and though little is known about the latter it seems scarcely credible that they could produce a *cooling* effect.

It is conceivable that there was some defect in the experimental technique, perhaps, for instance, the stray light from intense low aurorae may not have been sufficiently eliminated. Though this possibility is of course very remote it must be remembered that observational work on aurorae is very difficult. Experience has shown that it is necessary to be cautious. Some time ago several spectroscopists reported that measurements on the Doppler width of certain spectral lines definitely require that the temperature of the upper atmosphere is low even at considerable altitudes. L. Spitzer (**42**), however, has since shown that the instrumentation was inadequate and that no such conclusion was justified.

If a temperature of 340 deg. K. is correct, it is essential to revise completely our views on the structure of the upper atmosphere. The form the revision must take is not obvious. To account for the considerable scale height apparently required it might be suggested (in spite of what was said in Section 2.1) that hydrogen and helium become dominant constituents at moderate to great altitudes.

But this would leave unexplained the indications that oxygen and nitrogen are present in appreciable amount even near the 1000-km. level (*cf.* (ii) above) and further difficulties also arise.

On the whole it seems most judicious to accept the high temperature hypothesis (1500 deg. K.) and to regard the isolated contradictory evidence of the band spectra as anomalous in some way. The position is, of course, unsatisfactory, and further work is urgently required.

3. *The ionized layers*

3.1.—Knowledge on the ionosphere has been gained mainly through the use of radio probes. These enable measurements to be made on a number of the properties, including, in particular, the greatest electron concentration in a layer $n(e/max.)$ and the altitude of the level where it occurs $h(max.)$. The principle of the method is well known (**43**). Whether an electromagnetic wave is reflected by, or penetrates through, a given ionized layer, depends on its frequency ν. A critical frequency ν_c exists, such that there is reflection if ν is below it and penetration if ν is above it. $n(e/max.)$ controls, and can be determined from, ν_c: $h(max.)$ can be found from the time of travel of a wave up to the reflection level and down again. From the study of the variations of these, other quantities (such as the electron production rate and the local scale height) can be estimated. Details need not be entered into here.

During the past twenty years an immense amount of information relating to the ionosphere has been obtained by E. V. Appleton, L. V. Berkner, T. L. Eckersley, J. A. Ratcliffe and other radio scientists too numerous to mention. It is not possible for us to give an adequate account of this in the space at our disposal. With some regret we will neglect many interesting current topics (such as the discovery by D. F. Martyn (**44**) of great tidal motions in the upper regions) and will confine ourselves mainly to discussing the formation of the layers, which is the subject of most significance to astronomers, providing, as it does, evidence on the nature of the radiations entering the Earth's atmosphere. Before proceeding to do this we will give a very brief summary of the relevant experimental data.

No less than five distinct ionized layers exist, namely the E, F_1, F_2, D and sporadic E layers. The first three of these are of special importance and have been subjected to the most intensive study. Some basic information relating to them is given in Table V: the numerical values quoted are representative only. The D layer can be regarded essentially as a bank of ionization extending below the E layer. Comparatively little information on it has been published. It is known, however, that towards its base at 70 km. the electron concentration is about $3 \times 10^2/\text{cm.}^3$ (**45**). A striking feature of the D layer is the great intensification of the ionization during bright chromospheric eruptions. This, combined with the high collisional frequency, may cause so much dissipation of wireless waves passing through, that a radio fadeout ensues, it being impossible to use the upper layers as reflectors in long-distance communication (**46**). The sporadic E layer consists of patches of ionization embedded in the ordinary E layer. Very high electron concentrations (often greater than $10^6/\text{cm.}^3$) may occur (**47**).

3.2.—The variations exhibited by the layers through the day, the season, the sunspot cycle and at eclipses suggest that with the exception of sporadic E all result from the ionizing action of solar electromagnetic radiation. S. Chapman

TABLE V

The E, F_1 and F_2 layers

Layer	Altitude ($h(max.)$)	Atmospheric scale height, particle concentration, and constitution	Electron concentration $n(e/max.)$	Total rate of electron production	General remarks
E	120 km.	10 km. 6×10^{12}/cm.^{3}	$1{\cdot}5 \times 10^5$/cm.^{3} (day) 1×10^4/cm.^{3} (night)	6×10^8/cm.^{2} column	Behaviour regular. Diurnal, seasonal, and latitudinal variations follow simple theory.
		Molecular and perhaps atomic nitrogen : atomic and some molecular oxygen (layer being just above transition region).			Through sunspot cycle $n(e/max.)$ varies by factor $1{\cdot}5$.
F_1	220 km.	30 km. 1×10^{11}/cm.^{3}	$2{\cdot}5 \times 10^5$/cm.^{3} (day) (merged with F_2 at night)	$1{\cdot}8 \times 10^9$/cm.^{2} column	As E except that sunspot cycle variation is slightly greater, factor being $1{\cdot}6$.
		Molecular and perhaps atomic nitrogen : atomic oxygen.			
F_2	300 km.	70 km. 2×10^{10}/cm.^{3}	$1{\cdot}0 \times 10^6$/cm.^{3} (day) $2{\cdot}5 \times 10^5$/cm.^{3} (night)	$1{\cdot}5 \times 10^9$/cm.^{2} column	Behaviour irregular, variations anomalous.
		As F_1.			Through sunspot cycle $n(e/max.)$ varies by factor of about 4 (much more than in E or F_1).

(**48**), in 1931, developed the general mathematical equations governing the process. He showed that when the zenith angle of the Sun is ψ the rate of production of electrons at altitude h is given by

$$I(\psi, h) = S_0 n(X) A \exp[-n(X) AH \sec\psi], \tag{17}$$

with

$$n(X) = n_0(X) \exp(-h/H). \tag{18}$$

Here H is the local scale height (assumed constant within the layer), $n(X)$ is the particle concentration of the constituent X being ionized, S_0 is the number of ionizing photons incident/cm.^{2}/sec., and A is the absorption cross-section associated with the ionization process. $I(\psi, h)$ has a maximum

$$I(\psi | max.) = S_0 \cos\psi / H \exp(1), \tag{19}$$

where h has the value

$$h(max.) = H \log (n_0(X)AH/\cos\psi), \tag{20}$$

and $n(X)$ has the value

$$n(X/max.) = \cos\psi/AH. \tag{21}$$

The total rate of production of electrons/cm.^{2} column is given by

$$\int_{-\infty}^{\infty} I(\psi, h)\, dh = I(\psi/max.)H \exp(1). \tag{22}$$

To obtain an expression for $n(e)$, the electron concentration established, it is necessary to know R, the rate of recombination of the free charges. It is usual to assume a law of the form

$$R = \alpha n(e)^2; \tag{23}$$

α, which is called the effective recombination coefficient, may in certain circumstances depend on various factors such as the gas density, the negative ion concentration, etc. Now it is found that the diurnal variation of $n(e)$ is slow, except just before and after sunrise or sunset. Hence near-equilibrium conditions must prevail and it is permissible to equate the ionization and recombination rates; from (23) therefore,

$$n(e) = \{I(\psi, h)/\alpha\}^{\frac{1}{2}}. \tag{24}$$

It follows immediately that in the important case when α is a constant, the maximum of $n(e)$ is coincident with the maximum of $I(\psi, h)$, that is, its location is given by (20) or (21); further, its value $n(e/max.)$ is, from (19),

$$\{S_0/\alpha H \exp(1)\}^{\frac{1}{2}}(\cos\psi)^{\frac{1}{2}}. \tag{25}$$

These last results are of great importance as, of course, the radio probe measurements refer directly to the ionized layer itself rather than to the distribution of the ion production rate.

Examination of the experimental data shows that in the E and F_1 layers $n(e/max.)$ is closely proportional to $(\cos\psi)^{\frac{1}{2}}$. From (25) it is thus clear that α is almost constant in both. Conditions are less simple in the F_2 layer. It appears that here α is a decreasing function of the altitude and of the electron concentration. The former dependence has an important consequence, which will be referred to later; the latter should be borne in mind in any attempt at assessing the variation of the solar flux through the sunspot cycle from the variation of $n(e/max.)$.

The most obvious explanation of why there are several layers is that a variety of ionization processes are involved. To determine the nature of these is not an easy task, as the quantitative application of the general theory outlined above is seriously hindered by lack of precise information on the properties of the atmosphere, on the flux of solar radiation beyond the ultra-violet, and on the absorption cross-sections. As a result, advances have been uncertain. Indeed, it has been necessary to adopt to some extent the old-established method of trial and error; and conceivably the number of trials has not yet exceeded the number of errors.

We begin by discussing the location of the layers formed by the various possible ionization processes. The most convenient equation to use is (21), which gives the particle concentration at the maximum (and hence indirectly the altitude). Unfortunately very little is known about the absorption cross-sections A that

appear. Laboratory measurements on the atmospheric gases are difficult because of the very awkward spectral region that is involved. Quantal calculations are impracticable at present as far as molecules are concerned. Even for atoms they are of somewhat limited value. Laborious computations may yield a result that is grossly inaccurate—in the case of potassium for example, the A value is so sensitive to the form of certain wave functions appearing in the fundamental formula used, that it may only be estimated within a factor of perhaps a hundred. It is, however, possible to decide at an early stage whether or not a reliable answer can be expected. Oxygen is happily one of the elements that can be treated satisfactorily. Calculations by R. A. Buckingham, H. S. W. Massey, J. J. Unwin and the writer (**49**) show that for the photoionization process

$$O + h\nu \rightarrow O^+ + e \qquad (26)$$

the A value is $4{\cdot}5 \times 10^{-18}$ cm.^{2} at the spectral head, 13·5 electron volts, and remains large up to photon energies of at least about 25 electron volts: the true A value may perhaps be somewhat smaller but the error cannot be great (**50**). With only these scanty data it might well be thought unprofitable to attempt to decide the origin of the individual layers. However, as will be seen, considerable progress can in fact be made.

Consider the layer formed by process (26). If in equation (21) we take

$$A = 4.5 \times 10^{-18} \text{ cm.}^2 \text{ (the calculated value)},$$

$$H = 30 \text{ km. } (cf. \text{ Table V}),$$

$$\cos\psi = 0{\cdot}9 \text{ (a representative value)},$$

we see that $n(O/max.)$, the atomic oxygen concentration at the crest of the layer must be about 7×10^{10}/cm.^{3}, which is reasonably consistent with a total particle concentration of 1×10^{11}/cm.^{3}, the generally accepted value for the F_1 layer. Further, if the Sun approximates to a black body at 6000 deg. K., the flux of photons in the relevant energy range that arrives from it is about 9×10^8/cm.^{2}/sec., and is thus not significantly different from the observed integrated rate of electron production in the F_1 layer, which is $1{\cdot}8 \times 10^9$/cm.^{2} column/sec. It seems plausible, therefore, as suggested by H. S. W. Massey and the writer (**51**), to assume that the F_1 layer arises from the photoionization of atomic oxygen. No additional process is required to explain the F_2 layer. The decrease with altitude of the effective recombination coefficient (*v. supra*) can be shown to be sufficient to lead to a second maximum in the equilibrium electron concentration. This second maximum occurs well above the F_1 layer and its magnitude corresponds well with that observed for the F_2 layer (**52**).

It may be remarked that the observed integrated rate of electron production in the F_2 layer is $1{\cdot}5 \times 10^9$/cm.^{2} column/sec. which, when added to the corresponding rate in the F_1 layer, gives a combined rate of $3{\cdot}3 \times 10^9$/cm.^{2} column/sec. Comparison with the figure for the incident flux given earlier, suggests that the 6000 deg. K. black-body model of the Sun (on which it is based) may be a fair approximation at least as far as the emission of photons of energy 13·5 electron volts and somewhat greater is concerned.

Twilight observations provide some evidence on the ionic constitution of the layers, which supports the tentative views just given (**52**). Unfortunately O^+ itself cannot be detected, as it does not give rise to appreciable resonance scattering,

the oscillator strengths of all suitable lines in the visible part of the spectrum being extremely small. However, N_2^+ resonates strongly and the amount present can be estimated from the band emission during twilight. Analysis of spectroscopic data obtained by J. and M. Dufay (**53**) shows that the N_2^+ content of the ionized layers is minute. The simplest inference is that there is but a very slow rate of production of N_2^+ by photoionization,

$$N_2 + h\nu \rightarrow N_2^+ + e. \tag{27}$$

It would thus appear probable that this process cannot be responsible for the F_1 and F_2 layers—a useful elimination. In view of the constitution of the atmosphere in the region concerned, it can be seen that the only other possible alternative to (26) is

$$N + h\nu \rightarrow N^+ + e. \tag{28}$$

Like O^+, N^+ is such a feeble resonator that twilight observations can give no indication of whether or not a significant amount of it occurs. If there is considerable dissociation of the upper atmospheric nitrogen, it is not unlikely that (28) makes some contribution to the F_1 and F_2 layers: the flux of photons available for it is smaller, however, than the flux available for (26), as the ionization potential of N is higher than that of O (14·5 as compared with 13·5 electron volts).

If the hypothesis suggested is provisionally accepted (it cannot of course be regarded as established), further deductions can be made. As can readily be verified, photons of energy between 13·5 and well over 25 electron volts cannot reach much below the F_1 layer. In consequence, there is a severe limitation on the processes available for E-layer ionization.

Molecular oxygen is the only major atmospheric constituent with ionization potential less than 13·5 electron volts; ionization of it, which requires only 12·2 electron volts energy is therefore a natural process to consider. The flux of photons of the requisite energy is probably adequate. But a serious difficulty at once arises, for laboratory evidence suggests that ordinary photoionization

$$O_2 + h\nu \rightarrow O_2^+ + e \tag{29}$$

is very inefficient. M. Nicolet (**54**) has proposed, however, that a process termed pre-ionization may occur. In this, a molecule is first raised to an excited discrete level situated above the ionization potential; the level may be unstable and spontaneous ionization may ensue:

$$\left.\begin{aligned} O_2 + h\nu &\rightarrow O_2', \\ O_2' &\rightarrow O_2^+ + e. \end{aligned}\right\} \tag{30}$$

The A value associated with the band absorption is known to be very high, so that there is no inconsistency with the fact that the E layer is formed in a region where, owing to dissociation, the concentration of molecular oxygen is small. It must be emphasized that unlike the band absorption the spontaneous ionization has not been observed in the laboratory: that it takes place is an assumption.

Above an energy of 25 electron volts the photon flux from the 6000 deg. K. black-body model is very many orders of magnitude less than 6×10^8/cm.^{2} column/sec., the observed ionization rate in the E layer. However, recent work by H. Bondi, F. Hoyle and R. A. Lyttleton (**55**), on the theory of the corona, suggests that there *may* actually be a sufficiently intense emission of photons of energy a few hundred electron volts; F. Hoyle and the writer (**56**) have shown

that such photons might well yield a layer at the required altitude and having the required properties. It is clear that molecular nitrogen, as well as the other constituents, would be ionized. In view of the rarity of N_2^+ noted earlier, this is an unsatisfactory feature of the theory. The difficulty, though serious, is not necessarily insuperable, however, as conditions in the E layer are such that any N_2^+ formed may conceivably be quickly destroyed.

We thus see that there are two alternative theories of the formation of the E layer, the pre-ionization theory and the high-energy photon theory. Both must be regarded as speculative, since both depend on unproven assumptions. No final decision on either theory is possible at present.

A number of suggestions regarding the origin of the D layer have been made: various workers have advocated, for example, the photoionization of either *excited* atomic oxygen, molecular oxygen, ozone, or nitric oxide. The different theories were not developed sufficiently quantitatively for their merits to be properly assessed, but a few years ago it at least seemed not unduly optimistic to suppose that one of so many might contain the truth. A. and E. Vassy (**57**), however, have recently challenged this. From the study of absorption measurements they claim that only photons of energy less than 7 electron volts can penetrate below the 100-km. level. As such photons cannot ionize any atmospheric constituents other than the metals, they propose that these (including sodium in particular) are responsible for the D layer. It seems that such photoionization may yield an electron production rate of the required order near the base of the layer. But whether it can also do so in the body of the layer is more doubtful; a number of other apparent difficulties have to be elucidated before the theory can be accepted. Lack of published experimental data on the D layer greatly hinders progress.

Unlike the other layers the sporadic E layer does not arise from the action of solar electromagnetic radiation. This is clearly shown by the fact that it may be augmented during the night. The layer is actually composite in origin and is due to the ionizing action partly of charged solar particles and partly of meteors. The evidence for this comes from correlations with other manifestations of these agencies that have been established by E. V. Appleton, R. Naismith, A. M. Skellett and others (**58**). Comparatively little quantitative theoretical work has yet been done.

4. *Aurorae*

4.1.—Due mainly to the investigations of C. Störmer, L. Vegard and their associates, much is now known about the properties of aurorae. We cannot contemplate giving a full account of the observational data here; for compactness we must content ourselves in the main with listing briefly some of the salient facts that have been learnt.

(i) *General remarks.*—Aurorae are amongst the most conspicuous of natural phenomena. They may be grey, white, green, yellow, blue, violet or red, and may give as much illumination as the full Moon. A wide variety of distinct forms such as arcs, draperies and rays is observed. One of the most important and characteristic features is that the streamers lie along the lines of force of the Earth's magnetic field. The luminescence may vary rapidly in colour, intensity and position (**59**). But such prosaic statements yield no impression of the beauty of a great display and we will therefore give a selective précis from a striking

description written by C. Weyprecht and quoted by S. Chapman and J. Bartels in their book, *Geomagnetism* (**B**). First, referring to a quiescent aurora—" There in the south, low on the horizon, stands a faint arch of light. It looks, as it were, the upper limit of a dark segment of a circle; but the stars which shine through it in undiminished brilliancy, convince us that the darkness of the segment is a delusion produced by contrast. Gradually the arch of light grows in intensity and rises to the zenith. It is perfectly regular; its two ends almost touch the horizon, and advance to the east and west in proportion as the arch rises. No beams are to be discovered in it but the whole consists of an almost uniform light of a delicious tender colour. It is transparent white with a shade of light green, not unlike that of a young plant which germinates in the dark ". And again of a more violent display—" A scarcely visible band lies close to the horizon. All at once it rises rapidly and spreads east and west. For some time it remains stationary, then suddenly springs to life. Waves of light drive violently from east to west, the edges assume a deep red and green colour and dance up and down. Rays mount rapidly towards the zenith. The sky is in flames. This is an aurora in its fullest splendour: no pencil can draw it, no colours can paint it, no words can describe it in all its magnificence. Involuntarily we listen: such a spectacle must, we think, be accompanied with noise. But unbroken stillness prevails, not the least sound strikes the ear. Then once more it becomes clear, the whole phenomenon has disappeared with the same inconceivable rapidity with which it came and the gloomy night has stretched her dark veil over everything ".

(ii) *Geographical distribution.*—There are two zones of maximum auroral frequency. These approximate to circular rings of mean angular radius about 23° and with their centres at the geomagnetic poles. Near the maximum zones aurorae are of almost daily occurrence, but at low latitudes they are rare—in southern Italy for example they are only observed every few years (**59**).

(iii) *Temporal effects.*—Auroral displays have a tendency to recur after an interval of 27 days (the period of rotation of the Sun) and can sometimes be associated with the passage of a large sunspot group somewhat beyond the central meridian. They follow the general 11-year solar cycle. A close connection exists between aurorae and disturbances known as magnetic storms. Of particular interest is some evidence that indicates that both often begin about a day after chromospheric eruptions (**59**).

(iv) *Altitude.*—Many measurements have been made on the location in space of high-latitude aurorae. Essentially ordinary surveying methods are used, simultaneous photographs taken at several stations some distance apart providing the basic data for analysis. It is found that the mean altitude to which they descend is about 110 km. While more than nine out of ten aurorae end between the 90 and 130-km. levels, a few penetrate to rather below the 70-km. level and a few only reach down to the 200-km. level. The greatest altitude to which they extend is rather ill-defined and depends markedly on the auroral type. Average figures for arcs, draperies and rays are 140, 180 and 250 km. respectively, but these may be greatly exceeded; rays in particular are frequently observed well above the 400-km. level and when the atmosphere is illuminated by the Sun they may sometimes be traced to an altitude of rather more than 1000 km. (**59**). C. Störmer (**60**) has found that partially-sunlit auroral rays show a divided structure, a dark section being sandwiched between two luminous sections, a lower and an upper, the latter ending on the shadow line cast by the Earth.

The rarity of low-latitude aurorae makes them difficult to study, but information is gradually being collected. For instance, F. W. P. Götz (**61**) has estimated that 600 km. must have been the altitude of the summit of a great aurora observed in Switzerland and Tunisia during the night of 1938 January 25. From this and other cases it seems that the altitude of low-latitude aurorae is often considerable. Much has yet to be done, however, to provide data adequate for statistical purposes.

4.2.—Even a cursory inspection of the facts listed above suggests that the auroral luminescence is caused by the passage of charged particles through the atmosphere; it suggests also that these originate in the Sun. To proceed further and determine the properties of the particles is far from easy, as the investigations of K. Birkland, S. Chapman, V. C. A. Ferraro, C. Störmer, L. Vegard and others (**62**) have demonstrated. For an exploratory approach it is convenient to consider first the lag between solar disturbances and the commencement of auroral displays (*cf.* (iii)). It might seem reasonable to assume that the delay of about one day that appears to occur is simply the time of travel of the particles from the Sun to the Earth; if this is the case the speed must be about 1×10^8 to 2×10^8 cm./sec. Further, E. A. Milne (**63**) has shown that Ca^+ ions and other particles that produce strong absorption lines in the solar spectrum will, in certain circumstances, be subjected to an outward radiation pressure that will result in their ejection with just these speeds: following a suggestion made by S. Chapman (**64**) in 1929, R. S. Richardson and H. A. Brück and F. Ruttlant (**65**) have recently looked for, and found, some evidence for the existence of such a stream from the measurements on the distortion of the contours of absorption lines caused by the Doppler displacement effect. Moreover, it has been calculated that the action of the Earth's magnetic field will guide the Milne particles to the zone of maximum auroral frequency. All this seems very promising but, as was realized at an early date, a serious difficulty arises. The range R in air at S.T.P. of even 2×10^8 cm./sec. Ca^+ ions is only a little over 0·15 cm., whereas to account for the observed penetration of the auroral particles a much greater value is required: thus, for the deepest, average, and shallowest penetrations normally observed (*cf.* (iv)), R must be some 200, 0·5 and 0·01 cm. respectively (neglecting possible spiralling round the magnetic lines of force). Unless the estimates of the gas densities in the upper atmosphere are far too high, it would seem that we must arbitrarily invoke some other corpuscular emission. The particles most natural to consider initially are electrons and protons. Table VI summarizes some of their relevant properties: it gives for various speeds (or energies) the range R and the angular radius θ of the auroral ring resulting from the deflection of the particles by the magnetic field of the Earth; the former were obtained from laboratory data collected by N. N. Das Gupta and S. K. Ghosh (**66**), and the latter were calculated from formulae derived by C. Störmer (**67**). It will be noticed that electrons having about the required R give a θ much smaller than the observed 23° (*cf.* (ii)); protons are somewhat more satisfactory in this respect. The speeds involved for either are much faster than the 1×10^8 to 2×10^8 cm./sec. suggested by the one-day time delay (*v. supra*) and the corresponding energies are very high—they are comparable indeed with the energies arising from nuclear reactions. Superficially, at least, it would appear that the evidence favours protons (or perhaps somewhat heavier particles) rather than electrons. C. W. Gartlein (**68**), too, claims that broad displaced lines of atomic hydrogen are

emitted during auroral displays. The whole problem, however, is extremely complex (the outline given here being greatly over-simplified) and a final conclusion on the constitution of the incoming streams cannot yet be reached.

TABLE VI

Electrons				*Protons*			
Speed (10^9 cm./sec.)	Energy (10^6 e.V.)	Range R (cm. in air at S.T.P.)	Angular radius of auroral zone θ (degrees)	Speed (10^9 cm./sec.)	Energy (10^6 e.V.)	Range R (cm. in air at S.T.P.)	Angular radius of auroral zone θ (degrees)
1	0·0003	0·01	1·9	0·10	0·005	0·01	6·8
3	0·0026	0·04	2·4	0·25	0·033	0·05	8·6
6	0·011	0·2	2·9	0·5	0·13	0·2	10
12	0·047	3·4	3·5	1	0·52	0·8	12
18	0·13	18	4·0	2	2·1	7·5	15
24	0·34	83	4·7	3	4·7	30	16
27	0·66	220	5·2	5	13	190	19
29·7*	3·1	1300	7·1	10	53	3000	22

* i. e. 0·99 speed of light.

4.3.—We will now consider the spectra. L. Vegard and G. Kvifte (**69**) give the following as the main emissions from high-latitude aurorae: the green and red forbidden lines of $O\ \lambda 5577$ and $\lambda 6300$, band systems of N_2 known as the First Positive and Second Positive and the Vegard-Kaplan (which is a forbidden one) and a band system of N_2^+ known as the First Negative. R. Bernard (**70**) has also identified the forbidden ultra-violet doublet of $N\ \lambda 3466$, and M. Nicolet (**71**) has suggested that certain band systems of O_2^+ and NO may occur. Low-latitude aurorae have been less extensively investigated but all the emissions mentioned have been reported, with the exception of those from O_2^+ and NO, the absence of which is probably due to the change in the constitution of the atmosphere at the greater altitude that is usually involved for the more intense part of the luminescence. In addition the presence of the forbidden green doublet of $N\ \lambda 5199$, has been established by J. Dufay, J. Gauzit and Tcheng Mao-Lin (**72**).

By *forbidden* emissions we mean emissions resulting from transitions that violate the normal selection rules. They occur because the selection rules are only approximations, but the transition probability associated with them is extremely low—that is, the particle concerned remains on an average a long time in the excited state before it radiates (possibly many seconds instead of only about 10^{-7} or 10^{-8} seconds as for *allowed* transitions). Such emissions have been obtained from discharge tubes by J. C. McLennan, K. G. Emeléus, J. Kaplan and others (**73**) but the conditions have to be very carefully chosen. It might therefore appear remarkable that they appear prominently in the auroral spectrum. But there is no difficulty in explaining this. Atoms and molecules can readily be raised to the necessary excited states. In discharge tubes usually only a small fraction of them subsequently radiate, most instead are de-activated by impact with the walls. No walls exist in the upper atmosphere. Once excited (and we emphasize again that the relevant excitation probability is *not* abnormally weak) the atoms or molecules must eventually either radiate or give up their energy

in collisions with other particles; the gas densities are so low that the latter process does not predominate in general.

Perhaps the most interesting forbidden emission is λ 5199 of *N*. S. Pasternack (**74**) has calculated by quantal methods that the radiation lifetime of the excited state is about 10 hours. A striking verification of this longevity has been provided by F. W. P. Götz (**75**) who found that the strength of the doublet may continue essentially undiminished for hours after an aurora ends. From intensity estimates made on one occasion it seems that in the luminescent region (perhaps somewhat above an altitude of 200 km.) the concentration of *excited N* atoms was of the order 10^6/cm.^{3}—and it is not unlikely that the concentration of *N* atoms in their *ground* state may have been much greater. The non-appearance of λ 5199 in high-latitude aurorae is possibly due to the fact that the main emission usually arises from relatively low levels where collisions are sufficiently frequent to cause considerable de-activation of excited atoms of such great radiative lifetime.

Laboratory experience suggests that the *primary auroral particles* (whatever their nature) will eject sufficient *secondary electrons of moderate energy* from the atmospheric atoms and molecules they encounter for these to be responsible, directly or indirectly, for the greater part of the luminescence. The most obvious kind of collision to consider is one in which a secondary electron simply gives up some of its kinetic energy to cause excitation, which is then followed by emission, thus

$$\begin{cases} N_2 + e \rightarrow N_2' + e, \\ N_2' \rightarrow N_2 + h\nu, \quad \textit{First and Second Positive and Vegard-Kaplan band systems} \end{cases} \tag{31}$$

Ionization too might take place simultaneously, as for example

$$\begin{cases} N_2 + e \rightarrow N_2^{+\prime} + 2e, \\ N_2^{+\prime} \rightarrow N_2^{+} + h\nu, \quad \textit{First Negative band system} \end{cases} \tag{32}$$

While any of the observed lines and bands could arise from such processes, it may be shown that other processes *must* also be operative (**76**). The First Negative band system of N_2^+ is the most prominent in the spectra. If it results from (32), then for each of the numerous photons emitted a positive ion electron pair is formed. Now once an equilibrium state is reached the rate of disappearance of free charges must equal their rate of liberation. Hence the number of recombinations occurring must be very great. And as many of these must yield excited neutral particles the intensity of the ensuing emission must be considerable. A variety of reactions are possible, including

$$\begin{cases} N_2^+ + e \rightarrow N_2' + h\nu, \quad \textit{electronic recombination with emission in continuum} \\ N_2' \rightarrow N_2 + h\nu, \quad \textit{First and Second Positive and Vegard-Kaplan band systems} \end{cases} \tag{33}$$

$$\begin{cases} O + e \rightarrow O^- + h\nu, & \textit{electronic attachment with emission in continuum} \\ O^- + N_2^+ \rightarrow O' + N_2', & \textit{ionic recombination} \\ O' \rightarrow O + h\nu, \ N_2' \rightarrow N_2 + h\nu, & \textit{green and red forbidden lines, First and Second Positive and Vegard-Kaplan band systems} \end{cases} \tag{34}$$

and

$$\begin{cases} O_2^+ + e \rightarrow O' + O'', & \textit{dissociative electronic recombination} \\ O' \rightarrow O + h\nu, \ O'' \rightarrow O + h\nu, & \textit{green and red forbidden lines} \end{cases} \tag{35}$$

The relative importance of each of these and of processes like (31) and (32) depends on factors such as the energy of the secondary electrons, the degree of ionization established and the density and constitution of the atmosphere in the region concerned. It is not therefore surprising that the light emitted exhibits great colour variations.

The comparative brilliance of sunlit aurorae is due to resonance scattering by the N_2^+ ions produced along the track of the incoming corpuscles,

$$\begin{cases} N_2^+ + h\nu \rightarrow N_2^{+\prime}, \\ N_2^{+\prime} \rightarrow N_2^+ + h\nu, \quad \textit{First Negative band system} \end{cases} \tag{36}$$

It is instructive to consider briefly the special case presented by a divided aurora (*cf.* (iv)). The lower luminous section is caused by ordinary collision processes such as we have discussed. In the dark middle section the gas density is so small that these cause no detectable photon emission. The upper luminous section above the shadow line (where of course the gas density is still smaller) arises from resonance scattering and illustrates clearly its remarkable effectiveness (**77**).

While the presence of all the observed radiations can be accounted for in general terms the absence of certain others is difficult to understand. In particular it is very puzzling that the *allowed* lines of *O* are of such feeble intensity that they have not yet been identified with certainty.* It would have been anticipated that collisions between secondary electrons and oxygen atoms would lead to their emission,

$$\begin{cases} O + e \rightarrow O' + e, \\ O' \rightarrow O + h\nu. \end{cases} \tag{37}$$

There seems no obvious reason why (37) should proceed much less rapidly than (31) or (32). Until the anomaly has been explained, caution must be exercised in drawing conclusions about the constitution of the upper atmosphere from auroral spectra.

A peculiar feature is also associated with the relative rates of population of the various vibrational levels of the excited states involved in the emission of certain band systems. We will consider in particular the First Negative band system of N_2^+. The relative population rates can be derived from the intensities of the individual bands. We will denote them by r_n. The suffix indicates the particular vibrational level concerned; for the successive vibrational levels it is taken to be 0, 1, 2, etc. In Table VII we give the values of r_n obtained from (*a*) measurements

TABLE VII

First Negative band system of N_2^+

	r_0	r_1	r_2	r_3
(*a*) High-latitude aurorae	1·00	0·25	0·12	(0·05)
(*b*) Low-latitude aurorae	1·00	0·65	0·46	0·34
Effective vibrational temperature of N_2^+ (deg. K.)				
(*c*) Calculation (process (32)) 500	1·00	0·11	0·00	...
1000	1·00	0·13	0·01	...
2000	1·00	0·26	0·07	...
4000	1·00	0·47	0·22	...
8000	1·00	0·68	0·47	...

* Since this was written A. B. Meinel has reported the identification of strong allowed lines of *O* and *N* in the spectra of low-latitude aurora (**78**).

made on high-latitude aurorae (various altitudes but mainly about 120 km.) by L. Vegard and G. Kvifte (**79**), (*b*) measurements made on a low-latitude aurora (altitude 250–300 km.) by D. Barbier (**80**) and (*c*) quantal calculations carried out on the assumption that the excitation is produced by collisions between the secondary electrons and neutral nitrogen molecules (**81**). The units were chosen to make r_0 equal to unity.

As can be seen, there is a marked difference between high- and low-latitude aurorae, the diminution of r_n as n increases being more pronounced in the former than in the latter. The calculated values of r_n depend on the distribution of the nitrogen molecules among their vibrational levels, that is, on the *effective* temperature $T(v)$. To reproduce the observational results it is necessary to adopt a $T(v)$ *of about* 2000 *deg. K. in the case of high-latitude aurorae* (120 *km.*) *and a* $T(v)$ *of about* 8000 *deg. K. in the case of low-latitude aurorae* (280 *km.*). These figures are too great to be readily acceptable (*cf.* Sections 2.1 and 2.3). We are led therefore to suspect that some process other than (32) makes a considerable contribution to the emission. A plausible possibility is that part of the excitation is caused by collisions between *heavy* auroral particles (protons, etc.) and nitrogen molecules; laboratory experiments show that the r_n values resulting from such collisions fall off comparatively slowly with increasing n. If this explanation is correct, it would appear that the heavy particles postulated play a less important role in high-latitude aurorae than in low-latitude aurorae—a conclusion likely to be of considerable significance in the general theory. The difference between the calculated radii of the maximum auroral zones for electrons and protons (*cf.* Table VI) is perhaps not without significance in this connection.

5. *The Night-Sky Light.*—Even apart from the Moon and the stars and in the absence of aurorae the night sky is not completely dark. It, instead, glows feebly, the illumination produced on a horizontal plane being about equivalent to that from a candle at a distance of 60 metres. Spectroscopic studies show that discrete lines and bands are emitted. The identification of these has proved very troublesome owing to the very weak intensity and to the complexity of the spectrum; but progress has steadily been made, and as a result of the investigations of J. C. McLennan, J. Cabannes, G. Déjardin, J. Dufay, C. T. Elvey and many others (**82**), it is now known that the most prominent radiations are green and red forbidden lines of *O* λ5577 and λ6300, the *D* doublet of *Na* λ5894, the so-called Herzberg and Schumann-Runge band systems of O_2 and the Vegard-Kaplan and perhaps the First Positive bands of N_2. It will be noted that though the spectra of aurorae and of the night sky have a number of components in common, they are in some respects very dissimilar; the former may be described as one of high excitation energy and the latter as one of low excitation energy.

Attempts have been made at locating the region of the atmosphere from which the light is emitted. The method used can best be appreciated by drawing a sketch of a layer surrounding, and concentric with, a sphere representing the Earth. If this is done it can readily be seen that the apparent thickness of the layer (and hence its apparent brightness if it is luminous) depends on the observing direction. The mathematical expression for this dependence involves the mean altitude, which can thus in principle be found from measurements at different zenith angles. Unfortunately the results obtained up to the present are very discordant, altitudes ranging from below 100 km. to above 500 km. being advocated by various workers (**83**). This lack of agreement undoubtedly arises mainly

because of the difficulty of making proper allowance for the fact that the night-sky luminescence is not uniform and steady, but is, instead, patchy and variable. Some evidence favouring the lower limit is provided by the rotational structure of certain of the bands, which suggests that the temperature in the region that is concerned in their emission is only of order 200 deg. K. (**84**). Unless the conclusions reached in Section 2 are erroneous this indicates that the altitude cannot be above 100 km. All the radiations do not of course necessarily originate from the same level.

A number of theories on the source of the emission have been advanced by, amongst others, S. Chapman, S. K. Mitra, and T. Y. Wu (**85**). There now seems little doubt that at least part of the luminescence must be ascribed to the release of potential energy stored in the Earth's atmosphere. Two great reservoirs exist, the ionized layers and the region of dissociated oxygen (and perhaps nitrogen). We will consider these in turn.

While recombination processes similar to those that are thought to contribute to the auroral emission certainly take place in the ionosphere during the dark hours, it cannot be inferred that they are responsible for the night-sky light. As S. Chapman has emphasized, quantitative considerations are essential. In 1930 Lord Rayleigh (**86**), by determining the absolute intensity of λ 5577, provided the vital experimental information required to test any theory. His measurements show that in this line alone the mean rate of photon emission is $1{\cdot}8 \times 10^8$/cm.^{2} column/sec., so that the full emission during the night is about 10^{13}/cm.^{2} column. As there is no sensible diminution of the intensity even towards dawn, and as it is unlikely that all recombinations yield λ 5577, it can be seen that the total number of parent particles required is at least of order 10^{14}/cm.^{2} column, which is *considerably greater* than the total number of free charges in the layers. Similar arguments can be used to show also that most of the other radiations cannot be accounted for by reactions between ions and electrons. These are particularly convincing in the case of the nitrogen bands, for as we have seen the N_2^+ content of the ionosphere is very low. It is, too, extremely improbable that charged particles can be involved in any way in the excitation of those night-sky bands that are not enhanced during aurorae (*cf.* first paragraph of this section and of Section 4.3).

S. Chapman suggested in 1931 that two oxygen atoms on associating to form an oxygen molecule might give up their excess energy to excite some third body X which could then radiate:

$$\begin{cases} 2O + X \rightarrow O_2 + X', \\ X' \rightarrow X + h\nu. \end{cases} \tag{38}$$

Unless the altitude of the luminous layer is appreciably above 100 km. level, where collisions are infrequent, this possibility is very attractive, as the number of oxygen atoms available is vast (probably at least of order 10^{19}/cm.^{2} column). However, the amount of energy that can be given up on each collision is only 5·09 electron volts. Though this is sufficient to excite any of the night-sky lines and the Herzberg bands of O_2 it is *not* sufficient to excite the Schumann-Runge band system of O_2 or the Vegard-Kaplan and First Positive band systems of N_2 (which require 6·2, 7·0 and 7·3 electron volts energy respectively). Later workers were therefore led to the belief that atomic nitrogen might also be

present and that (38) might be supplemented by

$$\begin{cases} 2N+X \rightarrow N_2+X', \\ X' \rightarrow X+h\nu. \end{cases} \tag{39}$$

It is still a matter of controversy how much energy this might yield, but even the lower of the two values advocated by the different schools of molecular physicists is 7·38 electron volts and is therefore just sufficient. The position regarding the First Positive band system of N_2 is very interesting. In 1942 R. Herman, L. Herman and J. Gauzit (**87**) discovered an infra-red emission near λ 10,400 of extraordinarily high intensity (perhaps a hundred times more intense than λ 5577, the strongest line in the visible). It seems not unlikely that this can be identified with a band of the First Positive system arising from the zero'th vibrational level of the upper state involved. However, no band arising from the first, or higher, vibrational levels has been reported. It first appeared peculiar that such selective excitation could occur; but a simple and plausible explanation has been put forward by J. Stebbins, A. E. Whitford and P. Swings (**88**), who pointed out that if 7·38 electron volts really is the energy available from (39) then only the zero'th vibrational level could be excited, as the next vibrational level requires 7·5 electron volts energy. The proposed identification of λ 10,400 requires further verification; but if it should prove to be correct the intensity provides useful evidence on the amount of atomic nitrogen in the upper atmosphere—a recent provisional estimate gives the concentration near the 100-km. level as at least 4×10^{11}/cm.^{3}.

Because of the rarity of atmospheric sodium a special mechanism is clearly required to account for the emission of the *D* doublet. S. Chapman (**89**) has proposed that the reaction that liberates the sodium atoms from the sodium oxide presumed to be formed (*cf.* Section 2.2) also results in excitation:

$$\begin{cases} NaO+O \rightarrow Na'+O_2, \\ Na' \rightarrow Na+h\nu. \end{cases} \tag{40}$$

As can be seen a *two*-body collision only is involved. The low gas density therefore strongly favours (40) as compared with (38) or (39) which require *three*-body collisions.

Though it is widely accepted that association processes yield a considerable part of the night-sky light, there are certain aspects of it they cannot readily explain. Amongst these may be mentioned the patchiness and variability (to which reference has already been made), the correlations with magnetic activity, and the tendency for both the intensity and the irregularities to increase with latitude. Such effects suggest that there may often be a contribution to the emission due to the entry of charged particles into the atmosphere (**90**).

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SOLAR ACTIVITY

Sunspots.—Many sunspots appeared in 1948, yet the year was not really distinctive. The mean daily sunspot number, *R*, for the year was approximately 140. In April, *R* rose abruptly to 190, making it doubtful whether the maximum of the present 11-year cycle had, in fact, occurred about a year earlier, when in 1947 May, *R* reached the unequalled value of 206. In spite of the high average frequency of sunspots, 1948 had few striking features. There were no spot groups pre-eminent for size, as were the notable giant spots of 1946 and 1947. About a dozen groups did exceed 1000 millionths of the Sun's hemisphere at their maximum development, but none of these was outstanding for chromospheric activity. With this general mediocrity of activity, as differentiated from a high sunspot frequency, went an absence of marked geomagnetic activity and allied ionospheric disturbances, though both, in some measure, were not infrequently present. So much for the general picture, to which some details of interest may be added.

The three largest sunspots of the year increased in area to about 2000 millionths of the Sun's hemisphere, passing the central meridian respectively on February 16·3 (latitude 22° N.), April 25·8 (24° N.) and June 2·1 (11° N.). The full development of the first group was lost to observation after the rapidly growing spots had passed over the Sun's west limb. The group returned with an area exceeding 1000 millionths. A big, single complex spot, with a peak area of 1300 millionths, crossed the central meridian on May 12·3 (24° S.). The maximum field strength for this spot measured at Mt. Wilson was 3900 gauss. Among details of spot structure mention may be made of a freak umbra on April 2 at 9^h U.T. within a spot 18° east of the central meridian and in south latitude 14°. Apparently, the unusual horse-shoe shape of the umbra was produced by a temporary encroachment of photospheric matter over an otherwise circular umbra.

The most notable solar flare observed at Greenwich during the year occurred on May 21 from $11^h 20^m$ to $12^h 05^m$ over a sunspot region 70° west of the central meridian and 13° S. latitude. The observations of this flare and the associated phenomena, including an enormous burst of solar "noise", are recorded in *The Observatory*, **68,** 181, 1948. From the combined evidence of a radio anomaly and a geomagnetic crochet, an intense flare must also have occurred on March 20 from $12^h 24^m$ to $12^h 50^m$ for its more intense phase. Similarly, another flare was indicated on April 20 from $12^h 23^m$ to $13^h 05^m$, and a third one on December 9 from $11^h 49^m$ to $12^h 15^m$. Other short-wave radio fadeouts and bursts of solar noise suggest that in addition general high surges of solar activity occurred on April 1–2, April 13–16, May 12–13 and June 18–21. Generally speaking, however, both the observed and inferred flares were not of long duration, and were probably not extensive, as were the great flares of 1946 February 6 and July 25.

During 1948 nine geomagnetic storms were recorded at Abinger. Two of these (August 7–9 and October 17–18) were "great" storms, but neither was of unusual severity.

H. W. NEWTON.

Prominences.—The summary of prominences given below is based on data for the period 1947 December 1 to 1948 November 30.

The mean daily areas and numbers of prominences computed from the spectroheliograms taken at Kodaikanal on 263 days during the period are:—

	North	South	Total
Areas (in sq. min.)	2·10	1·94	4·04
Numbers	6·39	6·01	12·40

Compared with the previous year, the areas show a slight decrease in the northern hemisphere and a decrease of 27 per cent in the southern hemisphere; the numbers show a slight increase in both hemispheres. The distribution of areas in latitude shows pronounced maxima in the zones 75°–80° N. and 70°–75° S. with secondary maxima at 25°–30° in both hemispheres. Compared with the previous year this indicates a poleward drift of the zone of maximum activity. The largest number of prominences was observed at 70°–75° in both the hemispheres, the zones next in order of importance being 20°–25° N. and 30°–35° S.

Twenty-two metallic prominences were observed during this period with the prominence spectroscope, 11 in the northern and 11 in the southern hemisphere. Of these 13 were observed on the west limb.

Doppler displacements of the $H\alpha$ line in prominences were observed on 131 occasions with the prominence spectroscope. In 43 cases the shifts were towards red, in 40 cases to violet, while the rest showed displacements in both directions.

Observations with the spectrohelioscope in the $H\alpha$ line showed Doppler displacements on 71 occasions. Of these 18 were towards the red, 25 towards the violet and 28 in both directions simultaneously.

The mean daily area of $H\alpha$ absorption markings (without applying fore-shortening correction) is 3490 millionths of the Sun's visible hemisphere, representing a decrease of 24 per cent as compared with the previous year. The latitudinal distribution shows pronounced maxima in the zones 15°–20° N., 25°–30° N., 15°–20° S. and 30°–35° S., with a few secondary maxima in other zones.

A. K. DAS.

DOUBLE STARS

New Pairs.—Luyten and MacLeish (*P.A.S.P.*, **60**, 331) announce the discovery of two new faint binaries with large proper motion.

Measures.—Voûte publishes photographic measures in Part 3, and micrometer measures in Part 4 of Volume VI, *Annals of the Bosscha Observatory*, Lembang, Java. *Publ. U.S. Naval Observatory*, 2nd series, Vol. **15**, Part 4, contains measures by six observers. Other lists of measures are given by Rabe (*Veröff. München*, **2**, 1), Stein, Tibor and Pignatelli (*Ric. Ast. Vaticana*, **1**, No. 9), Van den Bos (*U.O.C.*, **5**, 134 and, by various observers, 192), Jonckheere (*J. Obs.*, **31**, 65), Mündler (*Heidelberg Veröff.*, **15**, No. 9), Muller (*J. Obs.*, **30**, 104), Aller (*Com. Obs. Santiago*, **1**, 4) and Podobyed (*A.J. Sovjet U.*, **24**, 357). Photometric measures of double star components are given by Miczaika (*Heidelberg Veröff.*, **15**, No. 6), Wallenquist (*Uppsala Ann.*, **2**, Nos. 2 and 3), and Muller (*Ann. Strasbourg*, **5**, 1).

Orbits:

Double Star	*P*	*e*	*a*	Computer	Reference
			″		
ADS 1631	283	0·54	1·20	Vidal	*P. Obs. Santiago*, **5**, 54
,, 2765	195·4	0·008	0·324	Arend	*B.A.B.*, **3**, 294
,, 7203	1067·1	0·814	6·20	Baize	*J. Obs.*, **31**, 33
,, 8032	74·85	0·51	0·58	Baize	*J. Obs.*, **31**, 33
,, 8739	115·7	0·443	1·256	Baize	*l'Ast.*, **62**, 55
,, 10087	131·96	0·6185	0·934	Rabe	*A.N.*, **276**, 60
,, 12889	224·68	0·7617	2·048	Rabe	*A.N.*, **276**, 49
,, 16538	137	0·8	...	Vidal	*P. Obs. Santiago*, **5**, 11
,, 16800	47·9	0·43	0·21	Russell	*P.A.S.P.*, **60**, 64
$1^h\ 30^m{\cdot}4\ -30°$	4·556	0·295	0·192	Voûte	*P. Riverview*, **2**, 64
$8^h\ 54^m{\cdot}2\ -42°$	21·02	0·15	0·62	Baize	*J. Obs.*, **31**, 33

Vidal (*P. Obs. Santiago*, **5**) writes on the apparent orbits of visual double stars; Rabe (*A.N.*, **276**, 49) on orbit correction by variation of the radius vector and its velocity; Rakowiecki (*Bull. Soc. Amis Sciences*, Poznan, Série B, No. 8) on orbit determinations by Thiele's method.

Miscellaneous.—Hirst (*M.N.*, **107**, 477 and *U.O.C.*, **5**, 172) derives the mass ratio and parallax of MlbO 4; Binnendijk (*A.J.*, **54**, 21) of ADS 11077; van de Kamp for various binaries (*A.J.*, **53**, 34, 39, 43, 165, 226) and has notes on the orbital interpretation for unresolved astrometric binaries (*A.J.*, **53**, 47) and the mass of the unseen companion in Zeta Cancri (*A.J.*, **53**, 207).

McLeod (*P.A.S.P.*, **59**, 316) writes on the nodal passages of visual binaries, Mateer (*P.A.S.P.*, **59**, 315) on the dwarf double star ADS 8242, Mannino and Rosino (*P. Bologna*, **5**, No. 6) on the position of the components of visual binaries in the Russell diagram and Jonckheere (*C.R.*, **226**, 65) on faint double stars and (*Obs.*, **68**, 150) on the outlook for double star astronomy.

W. H. VAN DEN BOS.

COMETS

The year 1948 proved to be quite as busy a one for observers of comets, and computers of their orbits, as 1947. Even excluding comet 1948 a, which has been counted as belonging to 1947, the number of new comets found was ten, a record—one more than in 1947—and it included one bright comet, the comet of the eclipse of November 1, which was a brilliant spectacle in the south during November. Three of these comets were discovered by Carl A. Wirtanen on the special proper motion programme plates made with the Carnegie astrograph at the Lick Observatory. No less than three of the new ones have been found to have orbits of short period: 1948 b, 1948 i and 1948 n. Two previously known periodic comets also were recovered, Forbes and Neujmin (1). In all, twenty-four comets were observed during the year (one more than in 1947) and included the two "annual" ones and ten from 1946 and 1947; and at the end of the year there were no less than fifteen comets considered to be still under observation.

The Schwassmann-Wachmann (1) and Oterma comets were as usual observed at around opposition and are not designated by annual lettering. The former,

at opposition in January, was recorded at around eighteenth magnitude, by G. van Biesbroeck at the Yerkes Observatory and H. M. Jeffers at the Lick Observatory, and followed till March, and from November onwards. Oterma's comet came under observation again in October, at seventeenth magnitude, and was the subject of special study at the Turku Observatory by Miss L. Oterma herself.

Of the other comets of the previous two years, Jones's comet 1946 h and Bester's 1946 k, were both observed again during the year. The former was photographed for the last time this year on November 23 by Jeffers at 19^m, and the latter by Van Biesbroeck on October 3 at 18^m. The periodic comet Faye, 1947 f, was followed till March 28 when it was 18^m (Jeffers). Whipple's periodic comet, 1947 g, which came to perihelion at the end of June (1948), was still under observation at the end of the year; it was recorded by L. Boyer at Algiers on December 29 as $14^m{\cdot}5$. Wirtanen's comet, 1947 h, was followed during the summer and until October 2 when Van Biesbroeck last photographed it, with the 82-inch reflector at the McDonald Observatory, and estimated its brightness as 20^m. The new periodic comet Reinmuth (2), 1947 j, was last photographed by Jeffers on February 1 and estimated as $17^m{\cdot}7$; a further attempt to do so in October was unsuccessful. Bester's comet, 1947 k, well observed early in the year, brightening to sixth magnitude in March, was last recorded by Jeffers on November 11 at eighteenth magnitude, but was considered still observable in 1949. The periodic comet Schwassmann-Wachmann (2), 1947 l, came to perihelion in the latter part of August and was about fifteenth magnitude early in January 1949. The bright southern comet, 1947 n, could only be followed till January 20, 1948, when Van Biesbroeck noted it as $10^m{\cdot}5$.

1948 a, the first comet announced this year, was actually first seen in Serpens on 1947 December 20, by Antonín Mrkos, at the Skalnaté Pleso Observatory in the Tatra mountains of Czechoslovakia, in the course of a systematic search for comets which is part of the regular programme there. It appeared as a ninth magnitude object without central condensation. Unfortunately, owing to twilight and a subsequent run of bad weather, it could not then be confirmed and was therefore not announced. Happily Mrkos himself succeeded in finding it again on January 18, then a diffuse object of tenth magnitude, with a short tail. Subsequently the position of an image of it, found on a plate taken on January 10, was reported by B. Protitch of Belgrade.

The comet remained at about tenth magnitude till the beginning of February, with a coma of about 2′ diameter condensed to a centre containing a faint nucleus. By March it had faded to thirteenth magnitude but was followed until December 5, when it was last recorded at the Skalnaté Pleso Observatory, at 16^m. The computation of the definitive orbit has been undertaken by E. Buchar (Prague).

1948 b was the intrinsically faint periodic comet discovered by Carl A. Wirtanen, in Taurus, on a plate exposed for two hours for the special proper motion programme with the Carnegie 20-inch ($f/7{\cdot}4$) astrographic camera of the Lick Observatory, on January 15·2. It was a diffuse object of the sixteenth magnitude, showing a tail about 1′·4 in length. The brightness was fading but the comet was followed till March 11 when a 90-minute exposure by Jeffers with the Crossley reflector showed it at nineteenth magnitude.

1948 c refers to an image, in appearance like that of a comet of fifth magnitude, found (at approx. $\alpha\ 7^h\,14^m$, $\delta + 69°$) near the edge of a photograph taken by

Keuskamp, a Dutch physician and amateur astronomer, on March 7·0. The presence of a comet was however not confirmed with certainty. Reports of observations of it on March 9 (8^m) at Leiden, subsequently stated to be not certain, and on March 15 (10^m) at Kiev (*Ast. Circ.*, U.S.S.R., 72), were published but are not supported by other evidence. A sky-patrol plate of the area taken at Sonneberg twenty-seven hours previous to Keuskamp's does not show any comet in the area, and other visual and photographic searches made after the announcement failed to locate it. The evidence therefore seems to be against this having been a real object.

1948 d, a comet of the tenth magnitude, was found first by Miss Ludmila Pajdušáková, in Hercules, on March 13·1 during a routine search for comets with the special Somet binoculars (100 mm., ×25) used for this work at the Skalnaté Pleso Observatory. She then wrongly identified it with a faint nebula, NGC 6615, shown in the new Skalnaté Pleso star atlas *. Antonín Mrkos, however, realized that she could not have seen this nebula with these binoculars and, later the same night, he was successful in locating and photographing the new comet with the 23½-inch Zeiss reflector.

It appeared a rather small object, 1½′ in diameter, with but little condensation, magnitude 10·5. It brightened but slightly as it approached perihelion ($q = 2{\cdot}1$ A.U.) in May, being then $9^m{\cdot}5$, of 2′ diameter, condensed to a bright centre with a stellar nucleus about $12^m{\cdot}5$, and having a tail seen as about 9′ long, in a 6-inch refractor (P. Brown). It passed within a few degrees of the North Pole in November and was still circumpolar and under observation at the end of the year, about thirteenth magnitude. The computation of the definitive orbit has been undertaken by V. Guth (Prague).

1948 e, the periodic comet Forbes, was detected by Hamilton M. Jeffers at the Lick Observatory with the 36-inch Crossley reflector ($f/5{\cdot}8$) on May 14·3. The two plates he exposed showed the small diffuse images of the comet within the "rays" of Spica. It was of the seventeenth magnitude, and though some three magnitudes fainter than expected, it was nearly in the position predicted by F. R. Cripps's elements. Later photographs showed a trace of tail. At perihelion in September the comet was still faint and only slightly brighter than fifteenth magnitude. It was recorded as of that magnitude when last observed at the McDonald Observatory, on October 2, by Van Biesbroeck.

1948 f, the periodic comet Neujmin (1) was detected by Seth B. Nicholson with the 100-inch reflector at Mt. Wilson on May 6.4 (i.e. before 1948 e), magnitude 17·5. A point of special interest about this comet has been its nearly stellar appearance and, on this occasion, it was reported as without coma. Actually two images of non-stellar objects were found on the plates, a little over a degree from the place predicted by Van Biesbroeck's elements, but the identification of the one attributed to the comet was confirmed by observations with the 60-inch reflector at Bosque Alegre (Argentine) by David McLeish in July and at Yerkes by Van Biesbroeck in September. It was last recorded this year by Van Biesbroeck on November 29 at fourteenth magnitude, and by McLeish on December 3.

1948 g was the comet first seen faintly with the naked eye, in Perseus on June 3·7 (*not* 2·7), by the Japanese amateur astronomer Minoru Honda, a farmer at Seto-mura (Hiroshima), and then confirmed with his 6-inch reflector. It was

* A. Bečvář, *Atlas Coeli Skalnaté Pleso*, Prague, 1948 ; also published by the Sky Publishing Corpn., Harvard College Observatory, 1949.

independently discovered the next night by the Italian amateur, Giovanni Bernasconi, at Cagno (Como) while sweeping for comets, and later on June 5 also by Tosikazu Higasi on board ship returning to Japan from the eclipse expedition of May 9. At discovery the comet was of magnitude $3\frac{1}{2}$, the coma having a diameter of 7′ or 8′ with a very bright centre and nucleus, and a tail several degrees in length. For a week it remained a faint naked-eye object. It faded slowly till July 4, when it was about $8^{m}\cdot7$, but then with the most unexpected rapidity, reaching sixteenth magnitude in mid-August and nineteenth on September 3 (Van Biesbroeck), nearly five magnitudes fainter than even the r^{-6} law predicted.

1948 h, another faint comet discovered by Carl A. Wirtanen this year, was found in Equuleus, also on a programme plate of the 20-inch ($f/7\cdot4$) Carnegie astrograph of the Lick Observatory, exposed for two hours on July 15·4. The trail showed a coma about 6″ in diameter with a central nucleus, and a tail about 2′ long, the total brightness being $15^{m}\cdot5$. It was then ten months before perihelion passage but the comet showed little brightening in the following months. Boyer and Van Biesbroeck gave its photographic magnitude as 14 early in September, but Jeffers as 16·5 on November 23, the last observation in this year.

The pursuit of this comet led Wirtanen to the discovery, on a plate exposed for the comet on July 18, of the interesting minor planet 1948 OA which passed the Earth at a distance of only 0·125 A.U. on August 10.

1948 i was the comet first discovered by Joseph Ashbrook, a Yale astronomer, while on a visit to the Lowell Observatory to observe minor planets, on a plate taken in Aquarius for 1327 Namaqua with the 13-inch refractor on August 26·3. It was found independently by Cyril Jackson at the Yale-Columbia Station at Johannesburg on a plate taken later the same day (August 26·8) while experimenting in the use of his small Aldis camera (20-inch focus, $f/5\cdot6$) for patrol work for fast-moving minor planets.

The comet was diffuse, centrally very condensed to a nearly stellar head or nucleus, and had a short tail, the total brightness being about eleventh magnitude. Johnson reported the tail as appearing semi-circular on plates taken at the Union Observatory on August 29·9, and a photograph taken at Oxford on September 12·0 showed a faint loop outlined which approximated to this description. Visual observers noted a coma of about $\frac{3}{4}'$ diameter, fanning out to 2′ or 3′, the nucleus being eccentrically placed in the forward part of the coma, and Van Biesbroeck's photographs of September 2 (*P.A.*, **56,** 447, 1948 October) show a skew appearance of the inner coma. The comet faded slowly and was still under observation, about fourteenth magnitude, at the end of the year.

The orbit was found to be elliptical, with a period of $7\frac{1}{2}$ years. L. E. Cunningham made a preliminary investigation of the previous path (*U.A.I.C.*, 1185) and found the comet had been in close proximity to Jupiter for several years around 1942, the minimum distance having been about 0·3 A.U. in July 1945. The effect was to decrease the size of the orbit so much as to reduce the period by about two years to its present value. As the comet must be a fairly large one to have been relatively so bright at its perihelion distance of 2·3, the present orbit, with its moderate eccentricity (0·4), gives hope that it may be possible to observe the comet, with large instruments, throughout most of its path.

1948 j, a faint diffuse comet, was discovered by Ernest Leonard Johnson, in Sculptor, on a plate taken with the Franklin Adams camera for the minor planet

programme, at the Union Observatory, Johannesburg, on September 1·8. Its magnitude was 13·5, a round diffuse uncondensed object. It had passed perihelion on April 9 but, at its comparatively large perihelion distance of 4·7 A.U., it moved away slowly and faded only to the fifteenth magnitude by mid-November. It was still under observation at the end of the year.

1948 k, the third faint comet discovered by Carl A. Wirtanen this year, was also found on a programme plate of the 20-inch Carnegie astrographic camera at the Lick Observatory, namely on one taken on October 7·2. It was a diffuse object of fourteenth magnitude, showing a tail about 1′ in length. It faded gradually and, when last photographed this year, on December 2·8, it was $15^{m}\cdot0$ (Boyer).

1948 l made a spectacular appearance at the total eclipse of the Sun on November 1, a very bright object, probably brighter than zero magnitude, within two degrees of the Sun's centre, with a long tail stretching down to the horizon. Photographs of the eclipse, taken from an aeroplane of the Royal Air Force in Kenya, while flying at a height of 13,000 ft., show good images of the comet and even some of the tail, although the exposures were only $\frac{1}{300}$ second (camera: 8-inch focal length, $f/5\cdot6$). The next certain report of it came from Captain Frank McGann of Pan American-Grace Airways, who found it independently, on November 4 while flying at 16,500 ft. near Kingston, Jamaica. Within three days it was reported as a new discovery by many others, in the southern hemisphere, who had been unaware of the observation of it during the eclipse. By that time its brightness had faded to about the first magnitude, but for some days it made a fine object in the southern skies, with a tail 20° long.

Van den Bos, observing it with the 9-inch refractor at Johannesburg on November 14·1, found a small, but not stellar, nucleus and a little "fountain" projecting from it towards the Sun, then curving back into the tail. A photograph taken at the Radcliffe Observatory at Pretoria on November 15·1, with a short exposure with a stationary camera of 7-inch focal length ($f/2\cdot5$), recorded a long straight faint streamer at an angle of about 9° to the main tail. Other photographs showed a number of streamers in the main tail—a series of sixteen long-exposure plates showing structural changes in the tail (see *P.A.S.P.*, **60,** 393) was obtained by Shane and Wirtanen between November 11 and December 10, with the 20-inch astrograph at Lick.

This comet maintained its intrinsic brightness well, and on December 20·5 was still of the sixth magnitude, with a coma of 5′ diameter, a nucleus of magnitude $10\frac{1}{2}$, and a tail visible for 2° in binoculars (Albert Jones). It was of the eighth magnitude when first seen in England, on December 30·0, and was well observed in the new year.

1948 m was a comet discovered by Michiel Johan Bester, in Volans, on a plate exposed for two hours in the 3-inch Ross R.B. camera, during routine patrol work at the Boyden Station at Bloemfontein on November 24·0, and confirmed by Johnson at Johannesburg the next night. It had a small head with a bright nucleus, hardly any coma, and a tail about 3′ in length. The total magnitude was 7·8. By the end of the year, when it was coming north, it had faded to about the eleventh magnitude.

1948 n, the second comet discovered by Minoru Honda, the Japanese amateur, this year, was found by him at the eastern end of Hydra, before dawn on December 3·9, while searching for comets: a diffuse object of about ninth

magnitude without, he stated, a nucleus or tail. It was independently found by Miss Ludmila Pajdušáková on December 6·2 during a routine search with a Somet binocular comet seeker (100 mm., ×25) at the Skalnaté Pleso Observatory in Czechoslovakia. Owing to the onset of twilight, however, she could not make certain of it and thought it to be the nebula M 83. The next night Antonín Mrkos, at the same observatory, not knowing of this, also found the comet during his sweeps, and confirmed it. Van Biesbroeck, observing it two days later, described it as having a centrally condensed coma some 2′ in diameter, with a nucleus, and a tail faintly indicated towards 290°. It faded with extraordinary rapidity, becoming an extremely diffuse object. Such diffuseness doubtless accounts for the discrepancies in the reported magnitudes. Between 1949 January 8 and 10, observations by Mrkos and Johnson indicated it was about fourteenth magnitude, while those by Van Biesbroeck and Jeffers made it seventeenth or eighteenth.

A. Schmitt (Algiers) found the orbit to be elliptical, with a period of about five years. He has undertaken the computation of the definitive elements. The preliminary elements, he has remarked, show a similarity to those of Biela's comet. A period of 5·3 years would imply a very close approach to Jupiter two and a half revolutions ago, about August 1935, when the comet would have been at aphelion and very near its ascending node.

In closing this review of 1948 it is worth recording that the situation as regards work on comets in the southern hemisphere was strengthened this year by the occasional use of the 60-inch reflectors at the Bosque Alegre Observatory in the Argentine, and at the Boyden Station of the Harvard College Observatory in South Africa, for recording comets when too faint for other available instruments; and also by the immediate computation of preliminary orbits by W. P. Hirst, an amateur astronomer at the Cape.

The table of the elements of cometary orbits which follows is arranged as in the last two reports: the comets are listed in order of perihelion date; the symbol P/ indicates a periodic comet, and *p* after the perihelion date that the elements were predicted ones. The perihelion date, deduced from observations, when not given in a set of elements in the table, will be found in the notes appended.

References and Notes to Table of Elements

1887 V P/Olbers. (1) Hans Q. Rasmusen, *Pub. Copenhagen Obs.*, No. 147, 1948. Definitive, being a revision of Ginzel's work, including recomputation of perturbations linking to 1815. Osc. epoch 1887 October 5·5. He predicts return: *T* 1956 June 15·9.

1916 II P/Neujmin (2). (2) G. N. Neujmin, *Bul. Poulkovo Obs.*, No. 141; **17** (6), 21, 1948. Definitive revision combining 1927 with 1916. Osc. epoch 1916 April 10·0.

1925 IV P/Tempel (2). (3) P. Ramensky, *Tokyo Astron. Bul.*, No. 615, 1942. Definitive, combining 1930 with 1925. Osc. epoch 1925 September 7·0. Yamamoto's *P.G.C.* makes it 1925 V.

1927 I P/Neujmin (2). (4) G. N. Neujmin, *Bul. Poulkovo Obs.*, No. 141; **17** (6), 23, 1948. Definitive, after combining with 1916. Osc. epoch 1926 October 12·0.

1929 III P/Neujmin (3). (5) Itaru Imai, *Journal Shanghai Sci. Inst.*, Section I, **1**, 1938. Definitive, from 30 observations covering 64^{d} around September 4. The accurate elements by Bowes and Willis, *L.O.B.*, **14** (417), 130, 1929, are in good agreement.

1930 VIII P/Tempel (2). (6) P. Ramensky, *Tokyo Astron. Bul.*, No. 615, 1942. Definitive, after combining with 1925. Osc. epoch 1930 November 20·0.

Table of the Elements

Comet		*T* G.M.T. before 1925·0 U.T. from 1925·0	*q*	*e*
1887 V	P/Olbers	1887 Oct. 8·4761	1·199109	0·930974
1916 II	P/Neujmin (2)	1916 Mar. 11·3155	1·339829	0·566493
1925 IV	P/Tempel (2)	1925 Aug. 7·0423	1·313284	0·560086
1927 I	P/Neujmin (2)	1927 Jan. 16·2336	1·338168	0·566823
1929 III	P/Neujmin (3)	1929 June 28·7421	2·042362	0·584538
1930 VIII	P/Tempel (2)	1930 Oct. 5·7896	1·318691	0·558856
1935 II	P/Reinmuth (1)	1935 Apr. 29·8733	1·855808	0·503718
		1935 Apr. 29·9138	1·855797	0·503853
1939 IV	P/Väisälä	1939 Apr. 26·0826	1·762299	0·634239
1942 VI	P/Wolf (1)	1942 June 23·5625	2·437385	0·404776
1943 V	P/Schaumasse	1943 Nov. 25·8050	1·202971	0·704347
1945 a	P/Pons-Winnecke	1945 July 10·5854	1·159230	0·654913
1946 a	Timmers	1946 Apr. 13·2635	1·724147	1·001201
1947 h	Wirtanen	1947 July 18·4598	2·827976	1·001045
1948 k	Wirtanen	1947 Sept. 4·7349	3·346054	1·0
1948 b	P/Wirtanen	1947 Dec. 3·5862	1·647932	0·560204
1948 a	Mrkos	1948 Feb. 16·6885	1·499362	1·0
1948 j	Johnson	1948 Apr. 9·3928	4·710514	1·0
1948 g	Honda-Bernasconi	1948 May 15·9062	0·207707	1·0
1948 d	Pajdušák.-Mrkos	1948 May 16·6228	2·106894	1·0
		1948 May 16·6233	2·106870	1·0
1947 l	P/Schw.-Wach. (2)	1948 Aug. 23·577*p*	2·152365	0·383651
1948 e	P/Forbes	1948 Sept. 16·1176	1·545187	0·552735
1948 i	P/Ashbrook-Jack.	1948 Oct. 4·7464	2·311069	0·395587
1948 m	Bester	1948 Oct. 22·917	1·27390	1·0
		1948 Oct. 22·9367	1·274137	1·0
1948 l	Eclipse Comet	1948 Oct. 27·4320	0·135335	1·0
1948 n	P/Honda-Mrkos-P.	1948 Nov. 17·7868	0·560295	0·815943
		1948 Nov. 17·5682	0·557655	0·809179
1948 f	P/Neujmin (1)	1948 Dec. 19·130*p*	1·544414	0·774568
1948 h	Wirtanen	1949 May 1·1170	2·517909	1·0

REFERENCES AND NOTES TO TABLE OF ELEMENTS (*continued*).

1935 II P/Reinmuth (1). (7) F. R. Cripps, *Handbook B.A.A.*, 1949. From differential correction of Kanda and Hirose's elements, with three (partly four) observations. Corrected value mean motion $n=0°\cdot1363003$ assumed. Osc. epoch 1935 January 30·0. *Handbook* value of *e* should read " 0·5037185 ". (8) G. Merton, MS. From differential correction of Foxell and Levin's predicted elements, with same three (partly four) observations, and Cripps's perturbations, and mean motion corrected for assumed error in applying perturbation $w.\Delta n$ instead of Δn, giving corrected $n=0°\cdot1362462$. Osc. epoch 1935 January 30·0.

1939 IV P/Väisälä. (9) Miss L. Oterma, *Handbook B.A.A.*, 1949. Definitive from observations covering 94^d. Osc. epoch 1939 March 18·0.

1942 VI P/Wolf (1). (10) M. Kamieński, *C.R.M. Acad. Pol.* (*Sci.*), 1948 January, No. 1. Definitive : his system Q4 satisfying observations 1925–1933/34–1943. Osc. epoch 1942 June 10·0.

1943 V P/Schaumasse. (11) Michael Sumner, MS. Accurate orbit after linking 1927 to 1944 observations. Osc. epoch 1944 March 31·0.

1945 a P/Pons-Winnecke. (12) J. G. Porter, MS. Semi-definitive, from 42 observations covering 126^d and linking with his 1939 definitive elements. Osc. epoch 1945 March 26·0.

of Cometary Orbits

Period (years)	ω	Ω	i	Equinox	Computer	Ref.	Comet
72·41	65°·3464	85°·3686	44°·5713	1950·0	Rasmusen	1	1887 V
5·43	193·7829	327·6716	10·6291	1925·0	Neujmin	2	1916 II
5·16	186·5834	121·1387	12·7710	1950·0	Ramensky	3	1925 IV
5·43	193·7315	328·0027	10·6325	1950·0	Neujmin	4	1927 I
10·90	140·7799	158·2191	3·6879	1929·0	Imai	5	1929 III
5·17	186·5991	121·1212	12·7569	1950·0	Ramensky	6	1930 VIII
7·23	8·7885	125·1723	8·0613	1950·0	Cripps	7	1935 II
7·23	8·8114	125·1674	8·0641	1950·0	Merton	8	1935 II
10·58	44·3449	135·5634	11·2707	1950·0	Oterma	9	1939 IV
8·29	160·9685	204·3420	27·3031	1950·0	Kamieński	10	1942 VI
8·21	50·9175	86·9276	12·0818	1950·0	Sumner	11	1943 V
6·16	170·1081	94·4551	21·6938	1950·0	Porter	12	1945 a
...	54·3233	128·9118	72·8475	1946·0	Schmitt	13	1946 a
...	9·3839	311·0980	97·3270	1950·0	Cunningham	14	1947 h
...	75·2808	121·5320	154·9503	1948·0	Cunningham	15	1948 k
7·25	344·0063	86·3178	13·4976	1948·0	Cunningham	16	1948 b
...	61·9224	198·5648	77·5402	1948·0	Cunningham	17	1948 a
...	191·8987	139·6973	53·2527	1948·0	Bobone	18	1948 j
...	317·0433	203·1328	23·1617	1948·0	Cunningham	19	1948 g
...	66·9064	246·9217	92·9202	1948·0	Schmitt	20	1948 d
...	66·9068	246·9203	92·9195	1948·0	Cunningham	21	1948 d
6·53	358·1003	126·0201	3·7239	1950·0	Rasmusen	22	1947 l
6·42	259·741	25·445	4·621	1950·0	Cripps	23	1948 e
7·48	348·8936	2·3126	12·5134	1948·0	Bobone	24	1948 i
...	274·2306	66·9461	87·6217	1950·0	Naur	25	1948 m
...	274·2552	66·9189	87·6233	1948·0	Franklin	26	1948 m
...	107·2609	210·2994	23·1239	1948·0	Cunningham	27	1948 l
5·31	184·2600	233·1548	13·1591	1950·0	Schmitt	28	1948 n
5·00	183·8282	232·9606	13·1460	1950·0	Cunningham	29	1948 n
17·93	346·7345	347·2207	15·0294	1950·0	v. Biesbroeck	30	1948 f
...	229·9276	119·8644	130·2686	1948·0	Cunningham	31	1948 h

1946 a Timmers. (13) A. Schmitt, *J.O.*, **31,** (12), 199, 1949. From 38 observations at Algiers, covering 264^d, with perturbations included. Osc. epoch 1946 March 21·0.

1947 h Wirtanen. (14) L. E. Cunningham, *H.A.C.*, No. 921. Represents seven observations covering 294^d, perturbations not included. Residuals around 1″.

1948 k Wirtanen. (15) L. E. Cunningham, *H.A.C.*, No. 966. Represents seven observations covering 14^d.

1948 b P/Wirtanen. (16) L. E. Cunningham, *H.A.C.*, No. 892. Represents seven observations covering 13^d.

1948 a Mrkos. (17) L. E. Cunningham, *H.A.C.*, No. 924. Represents 12 observations covering 123^d.

1948 j Johnson. (18) Jorge Bobone, *U.A.I.C.*, No. 1186. Represents six observations covering 26^d.

1948 g Honda-Bernasconi. (19) L. E. Cunningham, *H.A.C.*, No. 915. Represents 11 observations covering 9^d.

1948 d Pajdušáková-Mrkos. (20) A. Schmitt (Algiers), *U.A.I.C.*, No. 1152. From his own 14 observations covering 62^d. (21) L. E. Cunningham, *H.A.C.*, No. 938. Represents 12 observations covering 97^d.

1947 l P/Schwassmann-Wachmann (2). (22) Hans Q. Rasmusen, *Pub. Copenhagen Obs.*, No. 148, 1948. Prediction based on his previous work (*ibid.*, Nos. 106, 128). Osc. epoch 1949 January 4·0. Observations indicated T 1948 August 23·5978.

1948 e P/Forbes. (23) F. R. Cripps, *Handbook B.A.A.*, 1949. From prediction based on his 1942 orbit corrected by $\Delta T - 0^d{\cdot}5$, with 1948 T corrected by $-0^d{\cdot}07645$ (Cunningham), and a accordingly.

1948 i P/Ashbrook-Jackson. (24) Jorge Bobone, *H.A.C.*, No. 958. Representing 11 observations covering 67^d, with only two residuals exceeding $1''$.

1948 m Bester. (25) Peter Naur, *U.A.I.C.*, No. 1199. From three observations covering 31^d. (26) Kenneth Franklin (Berkeley), *U.A.I.C.*, No. 1202. From observations covering 31^d.

1948 l The Eclipse Comet. (27) L. E. Cunningham, *H.A.C.*, Nos. 971, 972. Representing 23 observations covering 35^d.

1948 n P/Honda-Mrkos-Pajdušáková. (28) A. Schmitt, *U.A.I.C.*, No. 1202. From five observations covering 33^d. (29) L. E. Cunningham, *H.A.C.*, No. 975. Representing 19 observations covering 34^d.

1948 f P/Neujmin (1). (30) G. van Biesbroeck, *A.J.*, **44,** 116, 1935. Prediction based on his revision of the orbit 1913–1931. 1948 December observations indicate T December 15·9, but residuals of several minutes of arc remain, indicating a further revision of the orbit will be necessary.

1948 h Wirtanen. (31) L. E. Cunningham, *H.A.C.*, No. 957. Representing 11 observations covering 73^d, with only two residuals exceeding $1''$.

Additional Notes

1889 VI P/Swift. Jessica Young Stephens : " Study of the orbits computed for comet 1889 VI "; *A.J.*, **54,** 48, 1948. She investigated the range of solutions in the elements with 85 observations covering 1889 November 16 to 1890 January 21, and found the value of the period could lie between 7·82 and 10·03 years; and computed the perturbations 1889–1916. She concluded that identity with comet 1916 II P/Neujmin (2), or with Barnard's unidentified comet of 1905 July 22·5, was not possible, and that no prediction could be made for a return.

1892 III P/Holmes. F. Koebcke : " On the Orbit of Comet Holmes (Part I—Preliminary Researches) "; *Poznan Reprint* No. 12, 1948. He has rediscussed the three available apparitions of 1892, 1899 and 1906, and, after a preliminary computation of perturbations, has obtained semi-definitive elements for them, preparatory to definitive work and prediction.

1943 I Whipple-Fedtke-Tevzadze. J. Gadomski : " Definitive curve of the total light variability of comet Whipple-Fedtke-Tevzadze (1942 g), deduced from 996 visual observations of more than 36 different European observers by the aid of a new formula in consideration of the dislocation in time of the curve relatively to the moments of passage of the comet through perihelion and perigee "; *Pub. Warsaw Univ. Obs.*, **13,** Part 1, Cracow, 1947.

1947 i P/Encke. Professor L. Matkiewicz has confirmed that he gave the element ϕ incorrectly in the elements predicted for 1947 (*U.A.I.C.*, No. 1090), as was suggested in the last report. The correct predicted value was $57^\circ\ 48'\ 31''{\cdot}8$, giving $e = 0{\cdot}846275$ and $q = 0{\cdot}340981$ instead of the values indicated in the table, *M.N.*, **108,** 128, ref. 14.

1947 l P/Schwassmann-Wachmann (2). Rasmusen's work on the orbit, noted in the last report (*M.N.*, **108,** 128, ref. 21) is now published in *Pub. Copenhagen Obs.*, No. 148, 1948.

P/Wolf (1). M. Kamieński : " The New Path of the Comet Wolf I "; *Bul. Acad. Polonaise Série A*, 1948. His painstaking investigations have revealed small but definite changes in the elements of the orbit, including the deceleration of the mean motion, after the very close approach (0·125 A.U.) to Jupiter in September 1922, which are not accounted for by the planetary perturbations as computed. Another paper (*ibid.*), " The Influence of Mercury on the Motion of the Comet Wolf I ", leads to the conclusion that the action of Mercury cannot be the cause of the secular deceleration of the motion. And a third paper (*ibid.*) gives the prediction for the return of the comet in 1950.

Origin of Comets. A. J. J. Woerkom : " On the Origin of Comets "; *B.A.N.*, **10**, No. 399, 445, 1948. A critical discussion.

R. A. Lyttleton : " On the Origin of Comets "; *M.N.*, **108**, 465, 1948. Develops a theory that the Sun, moving through extensive interstellar dust clouds, causes aggregations (comets) to form by accretion, each along an axis in the direction of the relative ant-apex, at distances of the order of several hundreds of astronomical units from the Sun.

CORRIGENDA

107, 112, Comet 1935 II P/Reinmuth (1), ref. 21, line 6. For " H. Summer " read " M. Sumner ".

108, 124, line 2 of first paragraph of " Comets ". For " 1910 " read " 1927 IX ", and delete the rest of the sentence.

108, 124, line 11 from bottom. For " period " read " periodic ".

108, 126, line 24. For " June 26 " read " June 25 ".

108, 127, line 16 from bottom. For " 15 inch- " read " 15-cm.".

108, 128, line 5 from bottom, P/Tempel (2). Add " The value of a 3·0437225, based on Ramensky's prediction (*M.N.*, **107**, 100, refs. 60 and 61), was assumed ".

G. MERTON.

ADDRESS

Delivered by the President, Professor W. M. H. Greaves, on presenting the Gold Medal of the Society to Professor Sydney Chapman

The Gold Medal of our Society has been awarded to Professor Sydney Chapman for his contributions to geophysics and solar physics, and particularly to the study of geomagnetic phenomena. It is my duty and privilege to-day to attempt to indicate to you the reasons which guided the Council, on this occasion, to the bestowal on Professor Chapman of the highest honour which our Society can confer. But I cannot try to review all of our Medallist's work—he has done too much for that; and I think that I can best perform my task if I devote this year's Presidential Address to a survey of some of his activities and to an attempt to review these against the general background of our expanding knowledge.

Terrestrial magnetism is normally regarded as a branch of geophysics, but it is very close to the border-line between geophysics and astronomy in the narrower sense, that is, astronomy which excludes from its objects of study the one planet which we are in a position to study most thoroughly. It is now well understood that in studying certain geomagnetic phenomena we are studying phenomena whose ultimate origin is on the Sun, and that measurements of such phenomena can often be regarded as measurements of some process which is going on on the Sun's surface. But terrestrial magnetism is not an easy subject; the phenomena which we observe at the Earth's surface are complex and it is no light matter to trace them back to their solar origin. It is perhaps natural for solar physicists to be mainly interested in the connection between disturbances on the solar surface and the occurrence of the abnormal fluctuations of the Earth's magnetic field which we call magnetic storms. It is even possible that some astronomers regard the study of relationships of this kind as the main reason for the existence of geomagnetism and geomagneticians. But there are other ways in which the Sun influences the terrestrial field, and only in comparatively recent years has the proposition that individual magnetic storms can be shown to be connected with individual solar disturbances gained anything like general acceptance. At the time that our Medallist commenced his geomagnetic career there was considerable scepticism about this. The following passages are quoted from a standard treatise by the late Dr Charles Chree, a recognized authority on geomagnetism, published in the year 1912 (**1**). " The existence of a relation between sunspots and terrestrial magnetism is widely known but its character is usually misunderstood. The only parallelism that may be regarded as fully established is that between the mean sunspot frequency of the year or season—not of the individual day—and the range of the corresponding diurnal inequality in the magnetic elements. . . . . When it comes to irregular changes of the magnetic elements . . . . an intimate connection with sunspots is much more open to doubt. . . . . The question as to the direct relationship between large magnetic storms and individual sunspots is a difficult one. That such a connection exists is not merely a popular belief but also the view of some authorities who have specifically studied the subject. . . . . In the meantime it is probably the wisest course to keep an open mind as to the existence of a direct connection between sunspots and magnetic storms, or as to the nature of the relationship between solar and magnetic phenomena on individual days ".

At this point I think it would be appropriate for me to give a brief account of the relations between solar and geomagnetic phenomena which in the year 1912 *were* generally recognized as established. It is well known that when there is no sign of any magnetic disturbance at all, that is on days when the recorded traces of the components of the Earth's field are quite smooth, there being no visible fluctuations on the records, the field does not maintain a constant value but exhibits a well-marked daily variation. For example, taking magnetically quiet days, as they are called, the trace of magnetic declination against time for London exhibits a maximum shortly after mid-day, the direction of the horizontal component of the field being then more westerly than the average. This noon excess of westerly declination over the average varies throughout the year, being some $5\frac{1}{2}$ minutes of arc in June and only about 2 minutes of arc in December. The intensities of the horizontal and vertical field components also undergo daily variations. Now it has been known for a long time that the daily ranges of the components of the Earth's magnetic field vary statistically with the sunspot cycle, the average daily ranges being greater in years of sunspot maximum. This could have been interpreted, in the absence of a full knowledge of the facts, as a relationship between magnetic disturbance and the solar cycle, the increased average daily range at sunspot maximum being, on this view, ascribed to the effect of magnetic disturbance. But by 1912 it was also a well-established fact that the variation of daily range with the solar cycle applied equally to magnetically quiet days alone, that is, to days when no magnetic disturbance seemed to be present; so the relationship which had actually been established between solar and geomagnetic phenomena was not, from the available evidence, a relationship between solar activity and magnetic disturbance.

The fact that the quiet-daily variations fluctuate with the sunspot cycle indicates that we are dealing with phenomena which originate on the Sun, and if they can be correctly interpreted they ought to lead to some information about something that is happening on the Sun. But the interpretation is difficult and it soon appears that the only hope lies in being able to trace out the whole process. This involves a study of the immediate cause of the variation of the magnetic field which we measure at the Earth's surface. It was suggested by Balfour Stewart that the variation was due to fluctuating electric currents in the upper atmosphere and that these currents are induced in masses of conducting air by their motion across the permanent magnetic field of the Earth. This hypothesis received some support from Schuster's researches; it has become known as the dynamo theory of the daily variation, the supposed action being similar to that of a dynamo, the Earth itself being the magnet and the moving air the armature, the windings of which are represented by the conducting ionosphere. Now if this theory be correct, then in so far as the air movements are ascribable to tidal action there should also be a lunar daily variation of the Earth's magnetic field, that is, a variation with a period of one lunar day or about 25 hours. Such a lunar daily variation is, in fact, known to exist. It is much smaller than the solar daily variation; for example, the range in magnetic declination of the lunar daily variation in London is about half a minute of arc, and it can only be revealed by an extended analysis in which the preponderant solar daily variation has to be removed first. The lunar daily variation varies with the phase of the Moon and in 1913 (2) our Medallist determined its Fourier harmonic components at Trivandrum, Bombay and Batavia, and compared the results with his deductions from the dynamo theory. He drew

particular attention to the fourth harmonic and showed that its size favoured the hypothesis that the conductivity of the upper atmosphere during the night hours was small compared with its value during the daytime.

In 1919 (**3**) he completed an extensive investigation of the solar and lunar daily variations, embodying new harmonic analyses of the data. For the solar daily variation he utilized the observational material from twenty-one different observatories, well distributed over the Earth's surface, for the years 1902 (sunspot maximum) and 1905 (sunspot minimum). For the lunar daily variation he used seven years' observations at each of five magnetic observatories, the years chosen being quiet as regards solar and magnetic activity. For both the solar and lunar variations the results at each observatory were subjected to Fourier harmonic analysis, and the coefficients of the Fourier harmonics were then treated by the method of spherical harmonic analysis. This presentation of the data forms in itself a solid and lasting contribution to knowledge, the facts being thereby given in a form suitable for theoretical discussion. This discussion was undertaken by our Medallist himself in the same paper, and he gave a detailed comparison of the harmonics with the deductions from the dynamo theory. I shall refer presently to the results which emerge from theoretical discussions of this kind, but first of all I propose to refer to an immediate conclusion which can be drawn from the harmonic analysis of the data and to a convenient method of displaying the results of this analysis.

The immediate conclusion is this: the spherical harmonic analysis shows that the field responsible for the solar and lunar daily variations can be separated into two parts; the predominant part is a field originating above the Earth's surface, but there is also a field originating within the Earth itself. This conclusion is, so far, a straight deduction from the data, no hypothesis being involved. The field within the Earth is presumably ascribable to induced currents and I don't suppose that any one seriously doubts that the predominant field arises from currents in the ionosphere. Now if we assume that these currents originate in a single spherical layer and if we can assign a height to this layer the current system can be deduced from the results of the spherical harmonic analysis. I show on the screen (Fig. 1) the current systems representing the solar daily variation for the equinoxes and the June solstice in a year of sunspot minimum. These current charts were constructed by Bartels and are copied from *Geomagnetism* by Chapman and Bartels (**4**) where other current charts, including charts for the lunar daily variation, will be found. You will notice the circumstance that the currents are much weaker for the night hemisphere, and I have already referred to our Medallist's conclusion, reached by a comparison of the data with the dynamo theory, that the ionospheric conductivity is reduced at night. The current systems were deduced on the assumption of a single spherical conducting layer at a height of 100 km. above the Earth's surface, but the results would be very little altered if the height were assumed to be 200 km. or 300 km. instead of 100. Of course we now know that there are two main ionospheric conducting layers and we must contemplate the possibility that the currents responsible for the daily magnetic variations are distributed between them, but it should be remarked that even if the fields were not due to ionospheric currents, current diagrams of this kind would still provide a most convenient synthetic representation of the observed facts. The same remark applies to the corresponding current diagrams for the fields responsible for magnetic storms, and I shall refer to our Medallist's work on storms presently. But I will

remark now that, as in his researches on the daily variations, his first task in his researches on storms was the elucidation of the facts and their synthetic representation by appropriate analysis. Such analyses are highly necessary before we can begin to theorize, that is, if the theorizing is to be profitable. In fact the synthetic analyses are a very necessary part of the technique of observation, and I have no hesitation in describing our Medallist as an eminent observational astronomer, who has contributed, quite apart from his work as a theorist, data which are essential to the complete study of solar physics, and which constitute a solid and permanent addition to knowledge.

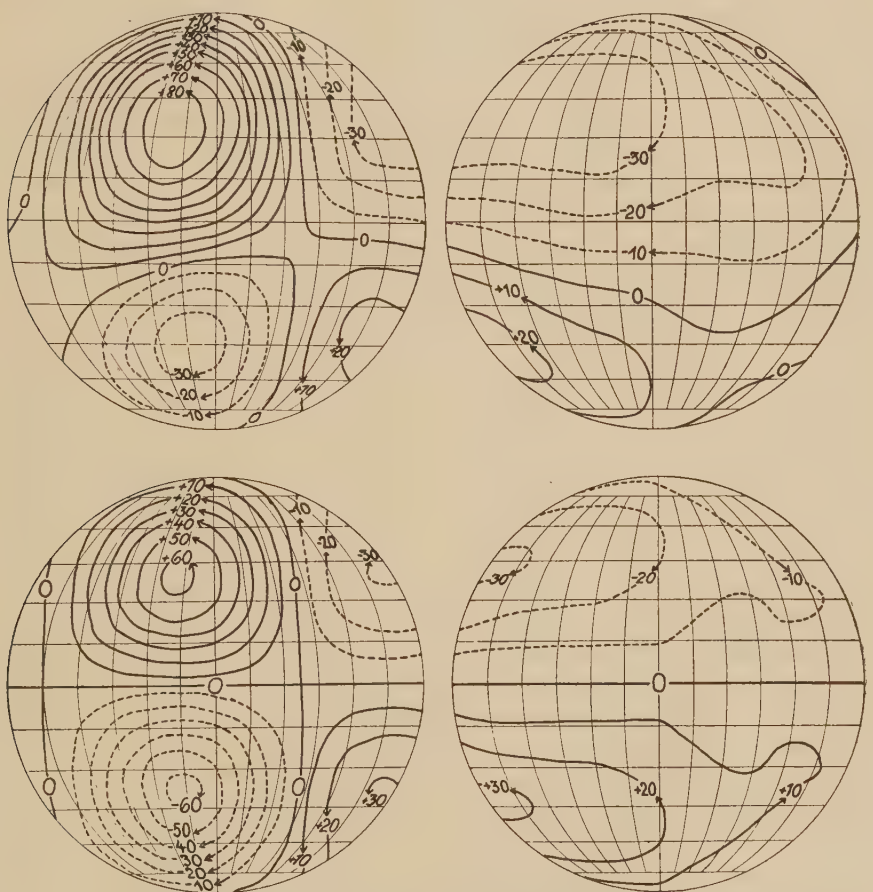

FIG. 1.—*Overhead electric current systems (at a height of* 100 *km.) corresponding to the solar daily variations at the equinoxes (top) and at the June solstice (bottom) in the sunspot-minimum year* 1902. *The sunlit hemisphere is shown on the left and the night hemisphere on the right. The Earth revolves within the current system and the meridians thus denote local solar time. Between consecutive stream-lines* 10,000 *amperes flow in the direction of the arrows.*

(S. Chapman and J. Bartels, *Geomagnetism*, **2**, 696, Figs. 1 and 2. *Diagram reproduced by courtesy of the Oxford University Press.*)

Returning to the daily variations, no one doubts, as I have already said, that their immediate origin is to be ascribed to ionospheric currents. It is when we come to consider the mechanism whereby these currents are produced that we enter the field of inductive theoretical enquiry. I have already mentioned that

our Medallist has applied himself to the development of the dynamo theory and to a careful comparison of its deduced consequences with the synthesized data. (I will add at this point that since the publication in 1919 of the paper to which I have already referred, our observational knowledge of the lunar daily variation has been expanded by another paper, published in 1925 (**5**), in which he gave the results of an exhaustive analysis of this variation from measurements made at Greenwich and other observatories.) He has found that although the dynamo theory explains many of the observed facts, it does lead to some difficulties. As regards the lunar daily variation, the semi-diurnal tidal convective motion in the ionosphere deduced by applying the theory is reversed in phase as compared with the lunar semi-diurnal barometric variation at the Earth's surface. To retain the dynamo theory we must assume that the lunar tidal convection is reversed at high levels. Again, although the analysis of the data shows the presence of the same principal harmonics in the solar and lunar daily variations, their mutual relations as regards magnitude and phase are somewhat different and there are other differences. To explain these differences on the dynamo theory it seems to be necessary to assume not only that the current systems responsible for the two variations are generated in two ionospheric layers and are mixed in different proportions in these layers, but also that there are important variations with ionospheric level of the solar and lunar daily convections. The necessity, if the dynamo theory is to be preserved, for making additional *ad hoc* hypotheses of this kind naturally indicates the desirability of examining alternative mechanisms for the production of the ionospheric currents; our Medallist has himself taken part in this very necessary task, and I regret that time permits me to make only a passing reference to his development in 1928 and 1929 of what he called the drift current theory (**6**) which he now considers, as a result of Cowling's further investigation of it (**7**), to be inadequate to account for the intensity of the solar daily variation field. At the present time there does not seem to be any serious rival to the dynamo theory; indeed, as regards the lunar daily variation, Chapman and Bartels remark in their treatise *Geomagnetism* that it is the only available theory that seems likely to be true.

It is natural that the main interest of astronomers in researches on the daily magnetic variations should centre on the information they give us as regards solar phenomena. Now I have mentioned that the solar daily variation changes with the sunspot cycle, and the same seems to be true for the lunar daily variation, for which, however, the proportionate change with the sunspot cycle is much less. It is now generally accepted that the daily variation fields originate from ionospheric currents and when the dynamo theory is applied it is found that the conductivity is much less by night. Probably the same result would follow if the necessary electromotive forces were generated by some other mechanism. The day and night difference in conductivity suggests ultra-violet solar radiation as the ionizing agent, and then the variation with the sunspot cycle would appear to indicate a variation of the Sun's output of ultra-violet radiation. Radio investigations lead independently to the same conclusion and indicate for sunspot maximum relative to sunspot minimum an increase of 130 to 160 per cent in the ionizing radiation. It should be noticed that long period changes of this kind in the solar output of ultra-violet ionizing radiation might be expected to affect the ionospheric currents responsible for the solar daily magnetic variation in two ways. The ionization, and so the conductivity, would vary with the sunspot cycle, but so would the heating effects due to absorption of the radiation, and accordingly the daily convective

motions of the air would change. This means that on the dynamo analogy both the conductivity of the armature windings and the rate of motion of the armature would vary, and each of these effects would produce change in the current system. But as regards the lunar daily variation, since the Moon's tidal action does not vary with the sunspot cycle, the influence of the latter on this variation would be confined to the change of ionization and conductivity in the ionosphere. This isolation of one of the two effects, both of which have to be considered in the study of the solar daily variation, justifies the great labour involved in the determination of the very small lunar daily variation.

I now turn to that part of our Medallist's activities with which some solar physicists will feel that they are most directly concerned, his researches on magnetic storms. Like his work on the daily variations, his investigations of magnetic storms can be divided into two parts. In the first place he applied himself to an analysis of the facts and to their synthetic representation; he then proceeded to examine the possible physical mechanisms. With regard to the first part of the research his experience in investigating the daily phenomena seems to have suggested the line of advance which was followed. In the study of the daily variations the first step is to isolate the variation at each observatory by an averaging process, the values of the magnetic field components at the same solar or lunar times on different days being averaged. A somewhat analogous procedure has been followed for magnetic storms. The characteristic of magnetic storms which first catches the eye on examining magnetograph records is the general disturbance of the traces, the magnetic field undergoing, during the period of the storm, violent fluctuations of short period. But it has been shown by our Medallist and by others that these fluctuations conceal features which are common to all storms. In 1918 (**8**), extending the earlier work of Moos at Bombay, he discussed the data from twelve observatories for forty magnetic storms of considerable though not outstanding intensity. The storms selected were characterized by what are known as "sudden commencements", the oscillations which we call a magnetic storm commencing suddenly at a definite time which, within a few seconds, is the same over the whole Earth. If the commencement be taken as the origin of time, then the time, reckoned from the commencement in this way, is called the "storm time". By averaging the measures of the magnetic field components for different storms at the same storm time our Medallist found that over the whole Earth, except perhaps in the close vicinity of the poles, the net mean change in the horizontal component during the first half hour or so is an increase. This is succeeded by a decrease of much greater amplitude, which lasts for several hours. A period of recovery then follows, which lasts for several days. Both the decrease and the recovery proceed most rapidly shortly after their initial stages and gradually slow down.

As regards the vertical component, it is slightly increased in numerical magnitude, both north and south of the equator, during the first day of a storm. Owing to the small amplitude of the change, it is more difficult than in the case of the horizontal component to determine the periods of increase and of subsequent recovery. The magnetic declination, or direction of the horizontal component, is hardly affected systematically, relative to storm time, in lower and middle latitudes. In higher latitudes a small change is observable, comparable in force units with that shown by the vertical component. I show on the screen a slide (Fig. 2) which is taken from this paper and exhibits these systematic variations of the magnetic field components; they are called the *storm-time variations*.

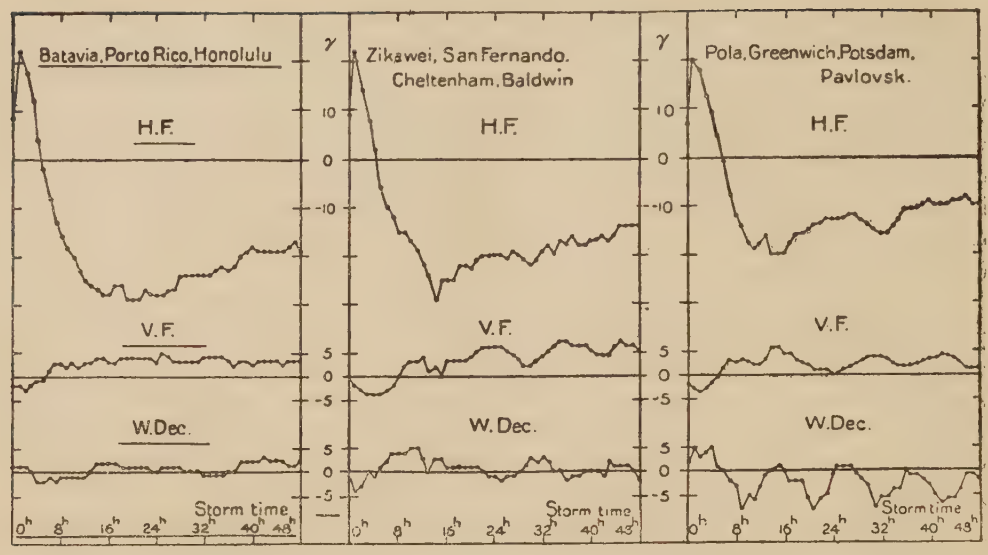

FIG. 2.—*Averaged storm-time variations for 40 magnetic storms.*
(S. Chapman, *Proc. Roy. Soc.* A, **95**, 65, Fig. 1, 1918. *Diagram reproduced by courtesy of the Royal Society.*)

In addition to establishing the storm-time variations, Chapman analysed the storm data for daily variations by averaging, for each observatory, the measured values of the magnetic components for the different storms at the same *solar* time. Now, in default of knowledge to the contrary, it might have been supposed *a priori* that this would merely reproduce the quiet-day solar daily variations, and that the storm-time variations would simply be superposed on these. But it had been known for a considerable time before 1918 that such was not the case and that the daily variation of the Earth's field revealed by an analysis of disturbed days is quite different from the quiet-day daily variation. The procedure adopted by our Medallist in his 1918 paper was to derive the average monthly mean daily variations for all days of the months of the forty storms considered, thus obtaining the ordinary daily variations corresponding to the place and season. He then subtracted these ordinary variations from the total daily variations found for the storms. This procedure isolates the daily variations characteristic of the storms *, which he has called the *disturbance-daily variations* †; they are additive to the normal diurnal variations. The disturbance-daily variations are most intense during the first day of a storm and gradually subside; in the main they consist of purely diurnal sine-waves and the phase relations of these waves in the different elements are notably simple. I show on the screen (Fig. 3) some of the results obtained by our Medallist for the twelve observatories (arranged in descending order of magnetic latitude). The figure refers to the horizontal magnetic component and displays the ordinary daily variation and the disturbance-daily variations for the first two days of a magnetic storm.

* This is not quite true. Since the storm days were included in the monthly averages the "ordinary" daily variations obtained include a fraction due to the disturbance-daily variations. Accordingly the analysis gives a daily variation which is not quite the total disturbance-daily variation.

† This is an example of the way in which Chapman has influenced the recognized nomenclature of the subject.

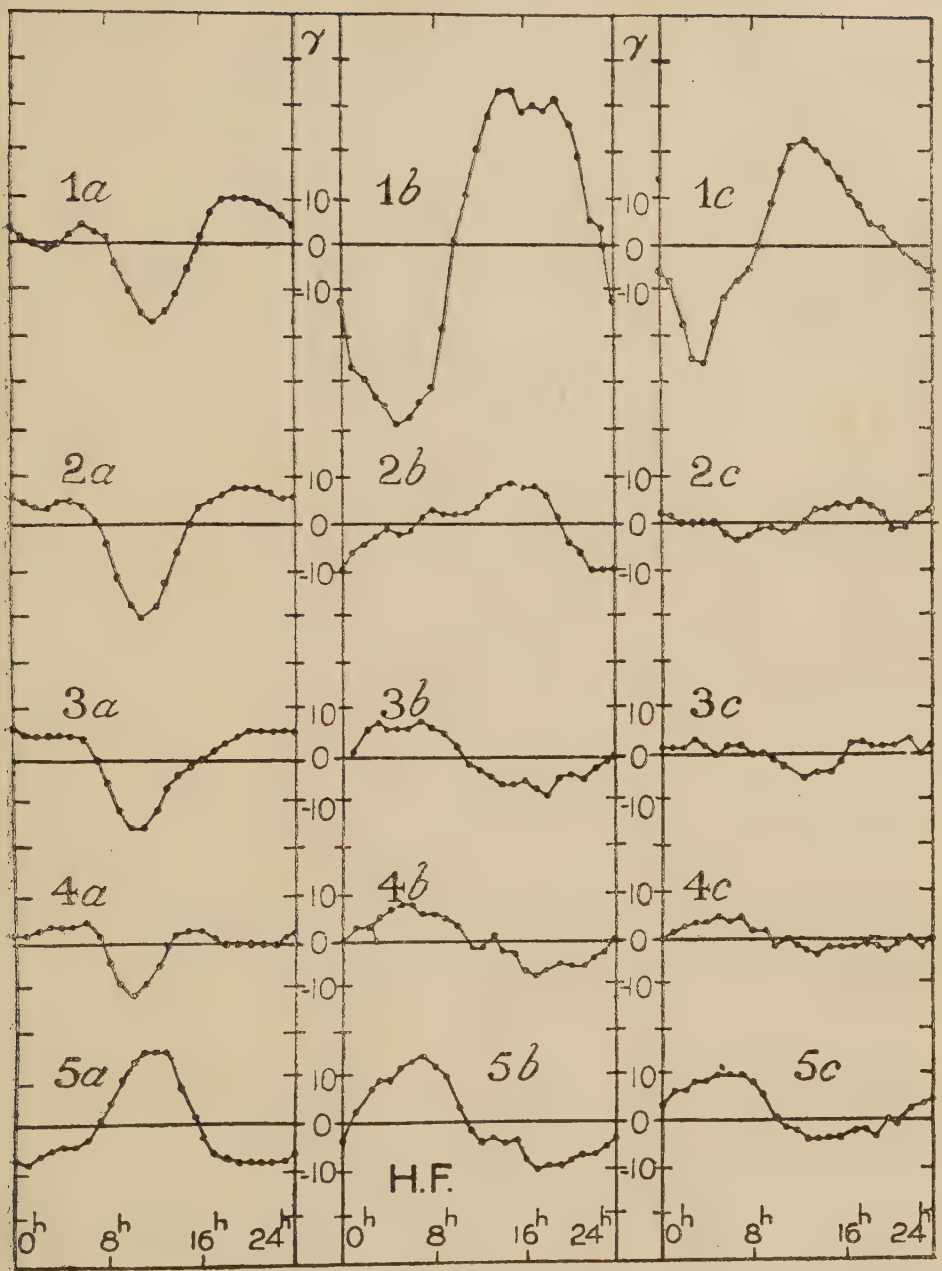

FIG. 3.—*Ordinary (a) and disturbance (b, c) daily variations in horizontal force; b, c refer to the first and second days of 40 magnetic storms. The sets of curves 1 to 5 refer to the following stations :—*

(1) *Sitka, magnetic latitude* 61°.
(2) *Pavlovsk, magnetic latitude* 58°.
(3) *Mean of Pola, Potsdam, Greenwich—mean magnetic latitude* 51°.
(4) *Mean of Zi-ka-wei, San Fernando, Cheltenham, Baldwin—mean magnetic latitude* 40°.
(5) *Mean of Batavia, Porto Rico and Honolulu—mean magnetic latitude* 22°.

The curves for Sitka and Pavlovsk have been smoothed by taking means of consecutive overlapping groups of three hourly values.

(S. Chapman, *Proc. Roy. Soc.* A, **95,** 68, Fig. 3, 1918. *Diagram reproduced by courtesy of the Royal Society.*)

Since the appearance of this paper the morphology of magnetic disturbance has received further study, in which our Medallist has himself taken part. Time permits only a brief reference to a paper published in 1927 (**9**) in which he showed that the characteristics of the larger magnetic disturbances, to which I have just referred, are also found in the minor disturbances. In the same paper he discusses the data for polar stations and finds that the disturbance-daily variation in the vertical component of the Earth's field reverses in phase as we pass across the auroral zone. The disturbance-daily variation in the horizontal component also undergoes a striking change of type within the auroral zone; this change, however, is not simply a reversal of phase as is the case for the vertical component. As regards the storm-time variations these are difficult to determine in polar regions from the available data, owing to difficulty in fixing the times of commencement, but our Medallist showed that there is an *average* decrease in the horizontal component over the *whole* storm period, as is the case for lower latitudes (where the decrease in the prolonged second phase overwhelms the initial increase, so that the average effect is a decrease).

The field responsible for the disturbance-daily variations can be represented by a system of ionospheric currents which is of a different type from the system which represents the quiet-day solar daily variations. I show on the screen (Fig. 4) Chapman's representation, and you will notice the great intensity of the currents (as indicated by the crowding together of the stream-lines) in the auroral zones and over the polar caps. The current system shown in this diagram is an idealized current system which relates to an ideal Earth having coincident magnetic and geographic axes. It provides a convenient and simple method of representing synthetically the features of the field; there is no implication here that the field actually is produced by such a set of currents flowing parallel to the Earth's surface in the atmosphere. Similarly the storm-time variations can be represented by an idealized system of ionospheric currents and the next slide (Fig. 5) shows such a system for the epoch of maximum intensity in the second phase of a storm when the total (smoothed) field strength is below normal. This current system is very simple in type; it consists of currents which are everywhere in the same direction, along circles of latitude from east to west. Within the auroral belt the current intensity is greater than elsewhere.

So much for the known facts of magnetic storms, in the elucidation of which our Medallist has been prominent. But these known facts have to be regarded now as symptoms; diagnosis is required, and at this point our Medallist becomes a theorist. In his 1918 paper he, quite naturally, sought for an explanation by a dynamo theory, just as for the quiet-daily variation field, and he supposed the current system to be actually located in the ionosphere and ascribed it to induction produced by vertical movements of the atmospheric layer concerned in the presence of the Earth's permanent magnetic field. The initial increase of intensity with storm time demanded, on this view, a downward motion which was considered to be due to the impact caused by the entry into the Earth's atmosphere of numbers of electric particles, mainly or entirely of the same sign of charge. The second or main phase of a storm during which the total field strength is decreased was ascribed to a subsequent upward motion due to the expansion of the layer as it acquired a charge from the incoming particles.

Our Medallist soon abandoned this theory, in consequence of criticism by Lindemann (**10**), on the grounds that a charged corpuscular stream from the Sun

would be dispersed by electrostatic repulsion in its passage to the Earth, and that even if such a beam of charged particles could exist, it could not impinge on the Earth for more than a few seconds on account of the charge that the latter would rapidly acquire. Lindemann suggested the existence of electrically neutral streams emanating from the Sun, but the polar properties of storm phenomena (as exhibited by the concentration of the representative current system in and within the auroral zones) seem to require that such a stream should be influenced by the permanent magnetic field of the Earth. Lindemann, in fact, suggested that the stream, at least when it reaches the Earth's neighbourhood, is neutral, but ionized. In 1929 our Medallist published (**11**) a paper on the geometry of solar streams of corpuscles in their passage outwards from the Sun, the velocities considered ranging from 100 km./sec. to 100,000 km./sec., particular attention being paid to a velocity of 1600 km./sec., this being the terminal velocity indicated for the ejection of atoms from the Sun as a result of selective radiation pressure, a process which had been previously investigated by Milne (**12**). Such a velocity would correspond to a time-interval of 26 hours from Sun to Earth, and this is the kind of figure suggested by the direct comparison of the occurrence of large magnetic storms on the Earth and of active eruptions on the Sun. This paper of Chapman's proved to be the prelude to the theory of magnetic storms by himself and Ferraro (**13**), which appeared in 1931 to 1933. I fear that my references to this theory will have to be brief and inadequate. The authors begin by postulating the existence of a corpuscular stream emitted from a limited area of the solar surface; the stream was supposed to be in existence for a considerable time, possibly for several rotations of the Sun, and the general effect may be compared with that produced by a rotating garden hose. As the stream rotates, it overtakes the Earth in its orbit, and the cross-section of the stream is assumed to be of the order of 1000 times the diameter of the Earth, so that by the time it is near the Earth the approaching face is nearly plane as viewed from the Earth. This plane face is only slightly inclined to the line joining the Earth to the Sun, but it should be observed that the particles in the stream are travelling nearly parallel to this line and the relative velocity of approach between the Earth and the plane face is nearly in the direction of the Sun. The stream, as it approaches the Earth, is assumed to be electrically neutral but ionized.

Chapman and Ferraro point out that (provided the stream density is not too low) an ionized stream is a conducting medium, and so, as the face of the stream approaches the magnetized Earth, currents would be induced which would be mostly confined to the surface layers of the stream. The reaction between these currents and the Earth's magnetic field would produce a repulsive force between the Earth and the material of the stream; this force would retard the advancing surface and in this way (provided the stream density is not too big) a hollow may, so to speak, be carved out in the advancing stream face, as illustrated in the next slide (Fig. 6). Chapman and Ferraro suggest that as the face advances the hollow would envelop the Earth, with the result that the magnetic tubes of force would be compressed inside the hollow and the Earth's surface field would be increased. We have seen that such an increase is characteristic of the first phase of a magnetic storm.

With regard to the second and longer phase, during which the surface field is decreased, Chapman and Ferraro point out that during the advance of the stream, in addition to the surface currents, there would also be surface charges induced by

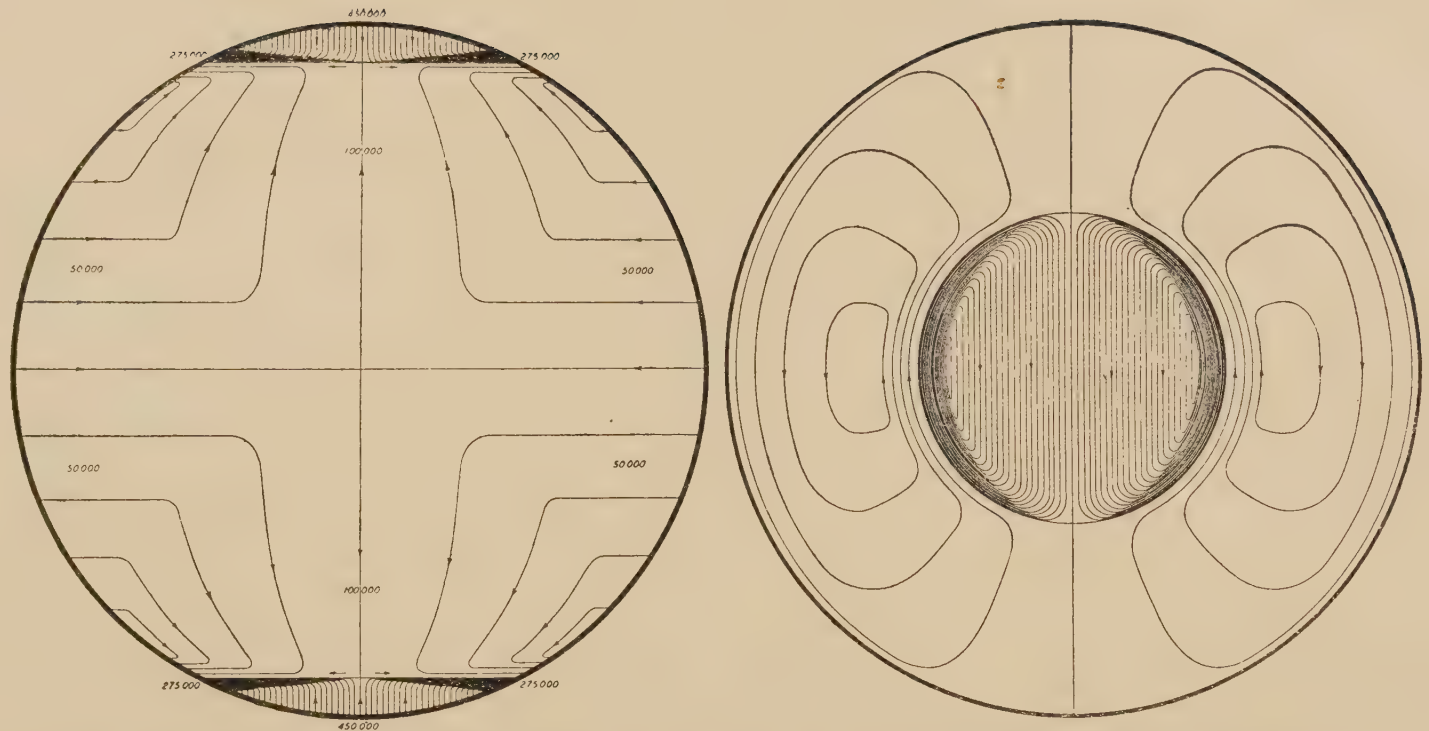

FIG. 4.—*The idealized overhead electric current system that could produce the disturbance-daily magnetic variations for 40 magnetic storms. Left :—View from the Sun. Right :—View from above the North Pole. Between consecutive stream-lines 10,000 amperes flow in the direction of the arrows.*

(S. Chapman and J. Bartels, *Geomagnetism*, **1**, 302, Figs. 21 and 22. *Diagram reproduced by courtesy of the Oxford University Press.*)

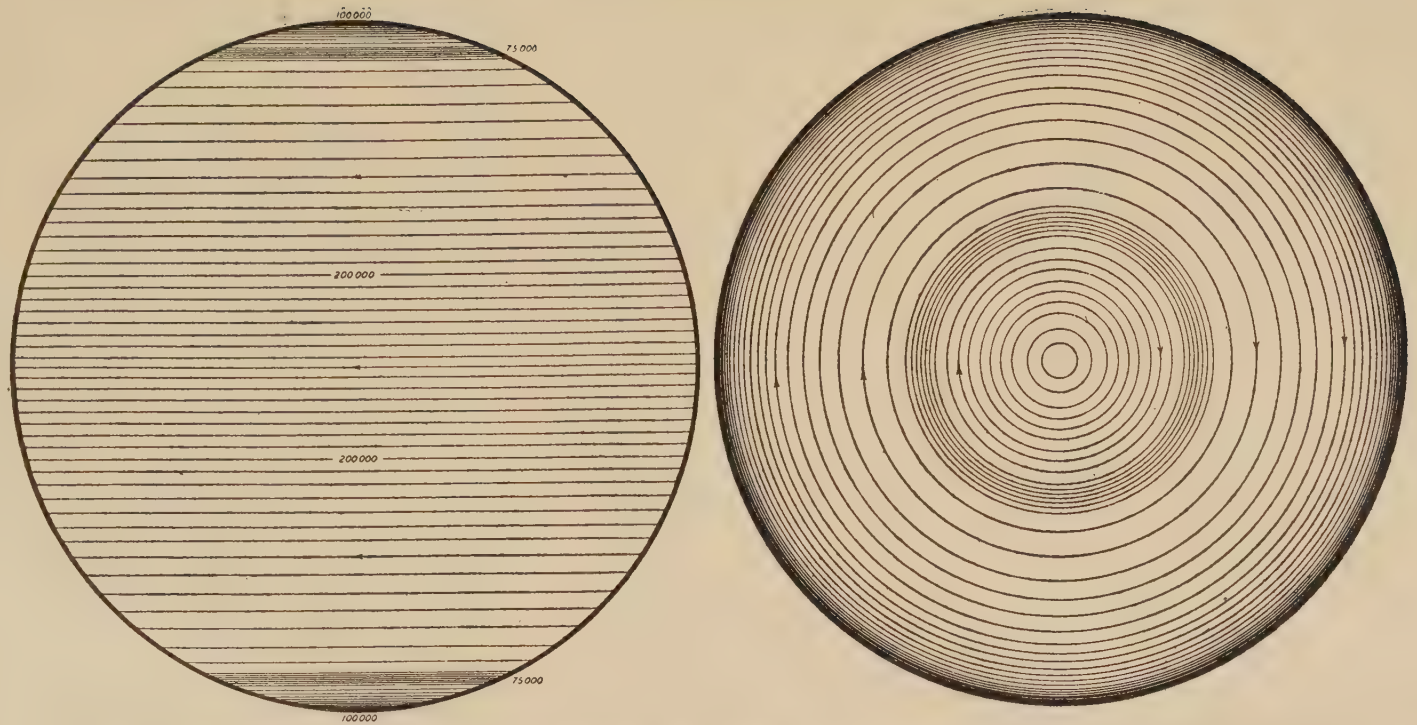

FIG. 5.—*The idealized overhead electric current system that could produce storm-time magnetic variations. Left :—View from the Sun. Right :—View from above the North Pole. Between consecutive stream-lines* 10,000 *amperes flow in the direction of the arrows. The figure refers to the epoch of maximum intensity (minimum total smoothed field strength) for the average of* 40 *storms.*

(S. Chapman and J. Bartels, *Geomagnetism*, **1**, 308, Figs. 23 and 24. *Diagram reproduced by courtesy of the Oxford University Press.*)

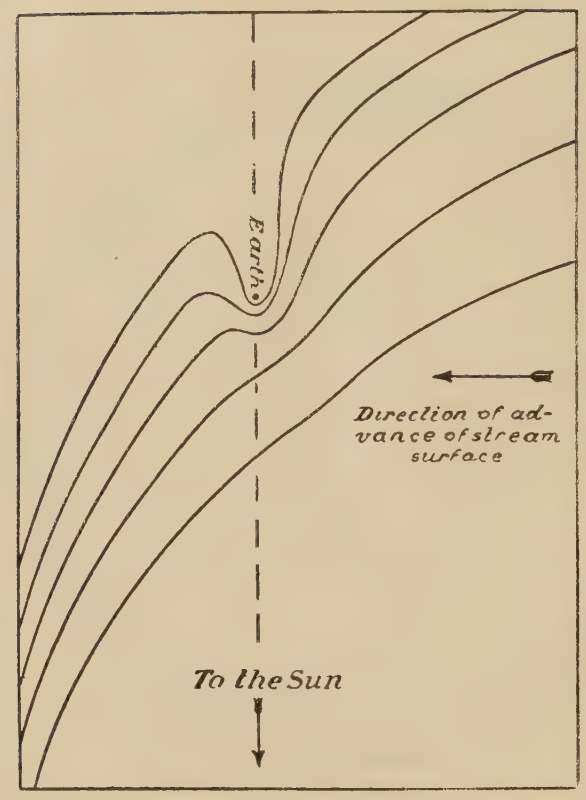

FIG. 6.—*Sections by the Earth's equatorial plane of the advancing front surface of a corpuscular stream, illustrating diagrammatically the formation of a hollow space round the Earth by the action of the geomagnetic field on the neutral ionized stream.*

(S. Chapman and V. C. A. Ferraro, *Terr. Magn.*, **36**, 174, Fig. 2, 1931. *Diagram reproduced by courtesy of the Editors.*)

the polarizing action of the Earth's field. The polarization would arise from the tendency of the magnetic field to deflect the moving ions and electrons in opposite directions, this tendency being resisted by the electrostatic field thereby produced. As a result of this action there would be a positively charged surface on the wall of the hollow opposite the *ante meridiem* hemisphere of the Earth (i. e. the hemisphere in which the local solar time is between midnight and noon), and opposite the *post meridiem* hemisphere the charges would be mainly electrons. The charges would tend to be repelled from the wall of the surface on which they lie and to cross to the opposite surface; whether they can actually leap the gap or not would depend on whether the radius of spiralling about the lines of magnetic force is comparable with the breadth of the gap or is much less than it. The spiralling radius is much larger for the ions than for the electrons and Chapman and Ferraro suggest that the ions will leap the gap, as illustrated in the next slide (Fig. 7), and will eventually create a current ring, the current being completed through the main body of the stream. They discuss the equilibrium and stability of such a current ring, electrically neutral but ionized, in which the ions travel with a velocity different from the electrons, and they suggest that the main phase of the magnetic storm is due to the field which the current ring would produce. Since the current is westward, its magnetic field is opposed to that of the Earth, so that the Earth's field will appear to be reduced.

Such is a qualitative sketch of the theory but, of course, as long as it remained a mere qualitative suggestion of what *might* happen, it would be of little scientific value, and before it could be dignified by the name of a theory it would be necessary to show by a quantitative discussion that at any rate a prima facie case could be made out for believing that it *could* happen, and could go some way towards accounting for the observed phenomena. The authors have endeavoured to perform this task as far as the first phase is concerned. They have made some progress, but they remark that as a result of their investigation the theoretical difficulties are exposed rather than overcome. As regards the second phase, the development of a current ring still remains a qualitative suggestion of what *might* happen, although as previously mentioned, the equilibrium and stability of such a ring, once formed, have been investigated.

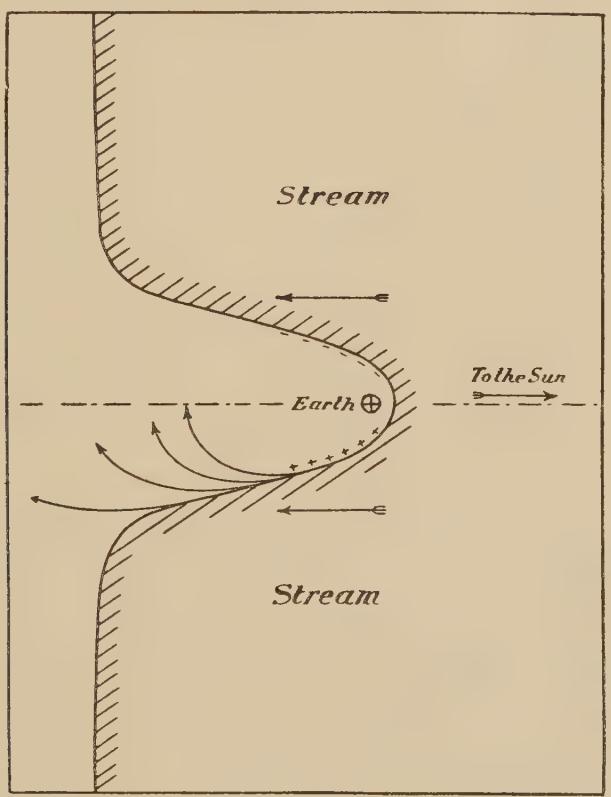

FIG. 7.—*Illustrating diagrammatically, in an equatorial section, the sign of the electric charges on the surface of the hollow carved in the advancing neutral ionized stream by the geomagnetic field. The curved arrows indicate the curved paths described, under the deflecting influence of the field, by charges which escape from the surface.*

(S. Chapman and V. C. A. Ferraro, *Terr. Magn.*, **36**, 181, Fig. 5, 1931. *Diagram reproduced by courtesy of the Editors.*)

Of course, even if further research showed that there was a good case for believing that these phenomena *could* happen, there would still remain the question of whether they *do* happen, and it will be instructive to examine the question of the existence of the corpuscular streams as contemplated by this theory in the light of our steadily expanding knowledge. In 1943, Newton (**14**) found that there was a very striking relationship between the occurrence of intense "flares" on the Sun

and the onset of magnetic activity on the Earth. This relationship was so strong as to make it very probable that some magnetic storms, including the "great" storms, originate from the more intense of the chromospheric eruptions which we call "flares". But an intense flare seems only to be followed by a magnetic storm if it occurs within about 45° of the centre of the Sun's disk, and, furthermore, there is an interval, of the order of a day, between the outbreak of a flare and the onset of the ensuing storm on the Earth. This interval indicates that the storm is primarily due to the impact on the Earth of corpuscular emission from the seat of the flare; and the fact that flares which occur at an angular distance of more than 45° from the centre of the disk do not seem to produce storms suggests that the corpuscular discharge from the flare area is roughly conical, the semi-vertical angle of the cone being about 45°. Now solar flares are short-lived phenomena, the life of an intense flare (Class 3^+) is only a few hours and a study of their spectroscopic characteristics shows that they usually attain their maximum strength in a much shorter time than this and then subside more slowly. It seems natural to suppose that the corpuscular emission is associated with the period of peak intensity of a flare when the $H\alpha$ line is asymmetrical (Ellison (**15**) has suggested that the asymmetry is due to absorption by hydrogen atoms in the departing stream). The duration of the emission would appear on this view to be very short—of the order of half an hour— and there is no evidence here for the existence of the comparatively long-lived "garden hose" streams of corpuscles envisaged by Chapman and Ferraro. The picture that the flare phenomena suggest is rather that of a conical blast of particles, and it is now the base of the cone and not the side which impinges on the Earth. But this change in the general picture does not seem materially to affect the theory, in which the essential initial process is the formation of the hollow as the face of the corpuscular discharge approaches the Earth. The face concerned is now simply the base of the cone.

An interesting point now arises. The period of corpuscular ejection from the flare area is short, being a few hours at the most, and probably much less than that. But the ensuing magnetic storm lasts for a day or more, and the question presents itself as to whether the duration of the storm is to be identified with the time during which the Earth is immersed in the corpuscular discharge. It is of course possible to assume *ad hoc* the necessary dispersion in the initial velocity of ejection of the corpuscles, but it is tempting to speculate that the impact of the main blast on the Earth only lasts for a period which is to be identified roughly with the duration of the first phase of the storm, say about half an hour or so, and that the process suggested by Chapman and Ferraro for the formation of a current ring can be invoked to permit the tearing off, by the action of the Earth's field, of a portion of the corpuscular blast, this detached portion being left swirling round the Earth after the main blast has proceeded on its way. Qualitative suggestions of this kind are, as has been previously remarked, of little scientific value in themselves, and the suggestion put forward by our Medallist and his collaborator with regard to the formation of a current ring still awaits full quantitative investigation. This will be a difficult task, but our attitude towards our Medallist with regard to matters of this kind is one of expectation.

The remarks I have just made apply to storms which originate from flares, and these seem to include most, if not all, of the "great" magnetic storms. But it seems now to be reasonably certain that there is a class of magnetic storms which does not originate from flare areas. It has been known for a long time that magnetic

storms, taken as a whole, show a marked tendency to recur after an interval of about 27·3 days, that is, after one synodic rotation of the Sun. But in 1929 it was found by Newton and myself (**16**), in discussing the Greenwich data for the period 1874 to 1927, that this recurrence tendency was confined to the smaller storms, and that the "great" storms showed no marked tendency to recur. As far as the "great" storms are concerned, this circumstance is now better understood; they seem to originate from intense flares, and a "great" storm will only be followed a synodic rotation later by another storm of the same type if another intense flare happens to erupt, which is a comparatively infrequent occurrence. But as regards the smaller storms, although some of these undoubtedly originate from flares and do not possess a marked recurrence characteristic, others apparently form a class of recurrent storms, which do not seem to be connected with the eruptions which we call flares. The 27-day recurrence indicates that these recurrent storms originate from limited areas of the solar surface and that the activity in these regions can persist for several solar rotations; Bartels has called them "M" regions. But until quite recently no evidence has been forthcoming which identifies the "M" regions with any recognizable solar activity.

If it be granted that there are "M" regions on the solar surface which are responsible for the recurrent magnetic storms, then it follows that there must be some form of stimulating emission from these regions. Is this emission corpuscular? Or does it consist, as has been suggested, of an emission of ultra-violet radiation? If it is corpuscular, then since the storms recur for several synodic rotations, the corpuscular beam must be long lived, and the theory of Chapman and Ferraro in its original form could be applicable to storms of the recurrent type. But it should be noticed that as far as direct evidence from a study of solar and terrestrial relationships is concerned, the evidence for corpuscular emission came from a study of the association between the larger storms and associated recognizable solar phenomena, and that this evidence seems to be missing when the recurrent storms are considered by themselves. There is actually some direct evidence in favour of the idea that the "M" regions produce magnetic storms by emission of ultra-violet light. A year ago Wulf and Nicholson (**17**) drew attention to sequences of magnetic disturbances whose onsets seem to coincide with the appearances, at the east limb of the Sun, of areas characterized in the earlier part of their histories as areas of bright hydrogen and calcium flocculi (not flares) associated with spot groups, and they point out that these areas contained almost all of the spot groups having large magnetic fields which occurred during the period they examined (1943 January to 1944 July: a period of sunspot minimum). Wulf and Nicholson suggest that these regions are "M" regions, and since the storm commencements synchronize with the appearance of the regions at the Sun's limb, they are led to suggest that the active agent is not a corpuscular beam but an outburst of ultra-violet light. Now in the case of flares, which we believe to produce storms by corpuscular emission, there are, in addition to the main storms which follow the flares after an interval, associated geomagnetic disturbances which are of short duration and which synchronize with the flares. These are the disturbances which we call geomagnetic crochets, and which we attribute to the action, on the ionospheric layers, of blasts of ultra-violet radiation from the flare areas. It is thus established that ultra-violet radiation from the Sun *can* produce magnetic disturbance on the Earth, and the suggestion put forward by Wulf and Nicholson seems to me to amount to this, that recurrent magnetic storms consist essentially

of an aggregation of movements of the crochet type. But crochets are only observable at magnetic stations situated in the daylight hemisphere, and it rather looks as if this suggestion about the nature of recurrent storms would involve a difference, for such storms, of magnetic activity between day and night. This suggests the desirability of further study of the morphology of storms in general and recurrent storms in particular, special attention being paid to the short-period movements and to the daily variation of disturbance.

My main object, on the present occasion, in making these last remarks is to try to illustrate the fact that geomagnetism is a live subject with many lines of investigation still to be followed. As with other live subjects, surprises are probably in store; we will not always find what we expect to find. I strongly suspect that our Medallist will provide us with some of the surprises, and with regard to problems such as those to which I have just referred, I think I may again say that our attitude towards him is one of expectation. I have attempted in this address, not to review all of his researches, but rather to give some idea of the way in which he has worked, and of the relation of his investigations to the general structure of our knowledge, towards the advancement of which he has made large contributions. In addition to actual geomagnetic research he has played an important part in the consolidation of knowledge gained; I have already made a passing reference to the comprehensive treatise on *Geomagnetism* by himself and Bartels (4), which was published in 1940. Besides his services to geomagnetic science he has contributed materially to the kinetic theory of gases, but on the present occasion I only have time to remark about this side of his activities, that he is a recognized authority on the subject, and that in virtue of this he has been peculiarly fitted to undertake the quantitative examinations required in the development of any geomagnetic theory, if it is to be called a theory. We are concerned to-day mainly with his geomagnetic achievements, but it is fitting that I should also refer to two other papers by him which appeared in our *Monthly Notices*; one, published in 1917, dealt with "Convection and Diffusion within Giant Stars", and the other, which appeared in 1922, was entitled "Diffusion and Viscosity in Giant Stars". In these papers he showed us the principles that must be followed in the solution of any problem in which we have to consider the variation of chemical composition which may occur between the centre and boundary of a star. Incidentally, in the second paper, he showed himself to be somewhat in advance of the time by contemplating the transmutation of hydrogen into heavier elements in the stellar interior, and he discussed briefly the rate of supply of hydrogen nuclei to the central region where the transmutation is proceeding and the hydrogen is thus used up. Those whose main interest lies in the field of stellar constitution and stellar energy may well regret that Chapman's incursion into their territories was only of the nature of a fleeting visit. Their loss has been geomagnetism's gain.

Professor Chapman:—You have served on the Council of our Society; you have been our President. There is therefore no need for me to inform you that the Gold Medal is not awarded lightly, but only after very careful deliberation. This medal symbolizes, among other things, our gratitude to you for what you have done in the advancement of geomagnetism and solar physics. You have undertaken the heavy but necessary tasks of analysing geomagnetic data, thereby presenting the facts in a synthetic form. Using these facts, in the establishment of which you yourself have played such a prominent part, you have applied your physical insight and theoretical skill to a painstaking exploration of possible processes which will

explain the phenomena. For these and other services to our science we are grateful, and I am voicing the feelings of every Fellow of our Society when I say that with our gratitude is associated a lively expectation of favours yet to come, and that we look forward to hearing you describe your own researches for very many years.

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